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RMP Acoustics

Services noise affecting dwellings

December 2007

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The authors gratefully acknowledge those who assisted in this project, in particular Mr D Shearer and Mr A Laidlaw for arranging access to measure a wind turbine installation.

The opinions expressed in this report are those of the authors.

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This report is published electronically to limit the use of paper, but photocopies will be provided on request to the Scottish Building Standards Agency

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Executive Summary

The Scottish Building Standards Agency (SBSA) propose to review whether the building regulations should address the issue of noise transmission to dwellings from domestic services installations. RMP Acoustics have been commissioned to provide information to aid SBSA with this deliberation.

The input, transmission and radiation of services noise in a building is complex. Services noise nuisance commonly occurs because the relevant expertise has not been commissioned to predict and mitigate this noise at the design phase. Even if the sound insulation of the separating wall and floor constructions are in line with Section 5 of the Technical Handbooks for the Building (Scotland) Regulations 2004, this is not necessarily sufficient to attenuate services noise to an acceptable level inside neighbouring dwellings. One reason for this is that there is a wide range of services noise emission levels, i.e. quieter services may be attenuated sufficiently by Section 5 constructions but noisier services would not be. Another reason is that services noise is often manifested as a result of vibrational energy input to the building structure which has been transmitted as structure-borne noise. The most effective way to avoid services noise problems starts with judicious location and then by specifying practicable noise and/or vibration limits for each piece of services equipment. Any residual noise can be reduced by enclosing the equipment, specifying an appropriate mounting and/or enhancing the sound insulation of the separating constructions.

The building services installations that have the potential to cause noise nuisance include common plant affecting dwellings (e.g. lifts), private plant affecting attached and detached neighbouring dwellings & private plant affecting rooms in the same dwelling.

From a review of key reference literature and international building regulations in conjunction with RMP's experience in domestic building services design and problem-solving to alleviate complaints arising from building services noise, we have presented our suggested criteria for consideration:

RMP suggested building services noise criteria		
All building services affecting neighbouring dwellings and all building services installations common to multiple dwellings (e.g. lifts) affecting them or neighbouring dwellings		
Bedrooms		≤ 30 dB L_{Aeq} ≤ 45 dB L_{AFmax}
Living rooms		≤ 35 dB L_{Aeq}
Less sensitive rooms: kitchen, toilet, bathroom		≤ 45 dB L_{Aeq}
Noise character	Impulsive and/or tonal penalty of 5 dB to the L_{Aeq} limit only	
Measurement period	Continuous noise	≥ 30 seconds
	Non-steady noise e.g. lift movement	Representative of complete cycle
	Intermittent noise	Measure during ON or HIGH setting
Frequency range	63 Hz to 4 kHz minimum	

The RMP suggested building services noise criteria is compatible with the BS 8233 Code of Practice (which is already well established in the UK building design industry) and the solid scientific knowledge collated by the World Health Organization.

This report raises a number of issues that would need to be considered in adopting the criteria; primarily whether to expand the application of the criteria to include:

- conversions and extensions as well as new-build dwellings (or differentiate between them);
- private services installations affecting the 'origin' dwelling;
- the potential for an interchangeable use of rooms;
- conservatories and private external areas (balconies, roof terraces);
- noise character penalty for intermittent sources;
- low frequency noise restrictions.

We have recommended that building services noise for new dwellings is subject to pre-completion measurements and we have recommended a measurement methodology. We have included an indication of the acoustician's fee for these measurements.

We have included sample design guides which give construction and installation advice for a particular installation in order to minimise the risk of noise nuisance complaints.

We have identified numerous British standards for specific building services product testing. However, we are aware that not all domestic building services suppliers are conducting the relevant testing, so reliable data is not always available to allow designers to include the appropriate noise control measures at the design stage.

1 Introduction

The Scottish Building Standards Agency (SBSA) propose to review whether the building regulations should address the issue of noise transmission to dwellings from domestic services installations. RMP Acoustics have been commissioned to provide information to aid SBSA with this deliberation.

The SBSA requirements were as follows:

> To provide information that would allow the Agency to develop draft standards and guidance on limiting noise transmission to dwellings from: lifts; refuse chutes; and other services (e.g. internal water pumps, integral substations, block heating, ventilation and air conditioning plant, and externally heat pumps and wind turbines) including associated pipe and duct work.
>
> a) Desktop survey:
>
> - the nature of the noise arising from services installations;
> - minimum acceptable performance standards for the level of noise within dwellings arising from lifts, refuse chutes and other services (both continuous and momentary);
> - standards for measurement and testing of noise from lifts, refuse chutes, and other services;
> - regulations in other countries concerning noise from lifts, refuse chutes, and other services (including an update of the research within Appendix A4.2: Protection against noise from installations of *Building Regulations in Europe Part II* [15]); and
> - existing industry guidance concerning noise from lifts, refuse chutes and other services.
>
> b) Design guides giving guidance on the design and construction of services installations.
>
> c) Measurement of noise from a micro wind turbine.

This report by RMP Acoustics contains:

- a list of typical domestic building services noise sources,
- a categorisation of building services noise emission,
- an indication of the noise source-to-receiver relationships for dwellings,
- a summary of key reference literature with respect to design criteria,
- a review of current Scottish planning conditions with respect to internal building services noise,
- a review of UK, European and international building regulations,
- our suggested minimum building services noise criteria and a discussion of options to expand or enhance it,
- a compliance assessment methodology,
- example design guides (for lifts, refuse chutes and pumps),
- a compilation of measurement & test standards for building services plant,
- indicative noise & vibration measurements from a wind turbine installation.

A glossary of acoustic terminology is provided at Annex A.

2 Noise sources, categories & configurations

Noise sources

Potential noise sources associated with building services or integral facilities serving communal or private parts of a residential building (dwellings only) are listed here:

- Lifts and associated plant
- Refuse chutes & storage areas (refuse or receptacle impacts)
- Air conditioning & ventilation systems: fans, condensers, ductwork breakout, grilles and other elements causing turbulent airflow and regenerated noise
- Heating systems: boilers, pipework, electric room heaters
- Water supply: pumps, whirlpool/jacuzzi baths
- Drainage: WCs, pipework
- Electrical: integral substations, generators, transformers
- Gas supply: pumps for high-rise buildings
- Low and zero carbon technologies: wind turbines, heat pumps
- Laundries: communal washing machines, driers
- Car park gates and roller doors/shutters

Noise from domestic appliances and portable equipment such as washing machines, dishwashers etc are outside the scope of this assessment as they are not considered to be building fixtures.

Noise categories

The Association of Noise Consultant's *ANC Guidelines - Noise Measurement in Buildings Part 1: Noise from Building Services* [1] identifies the following categories of building services noise:

Steady noise: Noise which is free from audible fluctuations in level or frequency content.

Non-steady noise: Noise which fluctuates audibly in level or frequency content.

Continuous noise: Noise from a source or sources which operate continuously.

Intermittent noise: Noise from a source or sources which cut in and out or change between prescribed settings. This might arise as a result of a single item of plant switching between settings, e.g. on, off, low, high; or changes in the number of machines operating at any given time.

Tonal noise: Noise which contains one or more audible tones.

Impulsive noise: Noise which contains audible impulses.

The following table is an indication of one or more of the noise categories that could apply to different types of noise-emitting building services equipment.

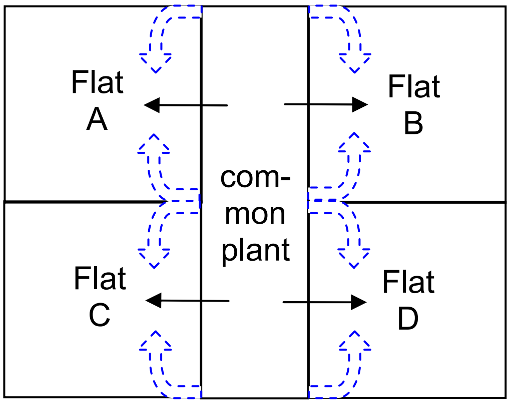
Noise source	Continuous	Intermittent	Tonal	Impulsive	Steady	Non-steady
Lifts		●	○	●		●
Refuse chutes		●		●		●
Air conditioning & mechanical ventilation	●	●	○	○	●	
Boilers	●	●	○	○	●	
Pumps	●	●	○	○	●	
Water pipework		●	○	○		●
Electrical	●		●		●	
Micro wind turbines	●	●	●			●
Laundries		●		○		●
Car park gates/doors		●	○	●		●
● normal operation ○ abnormal operation, i.e. installation/maintenance problem						

Noise source & receiver configurations

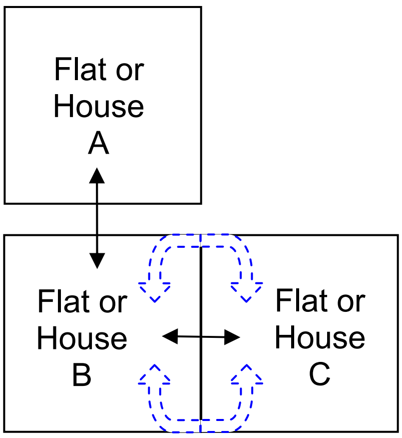
The following schematic diagrams explain the possible building services noise source and receiver locations for single and multiple occupancy residential buildings:

direct noise transmission

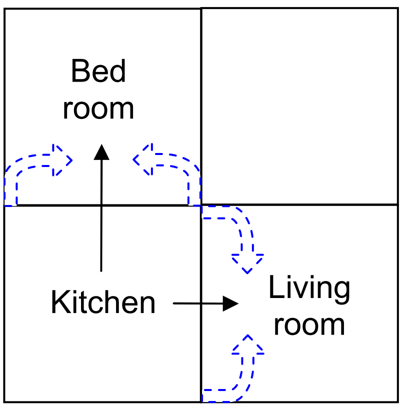
flanking noise transmission



Common plant affecting dwellings



Private plant affecting attached and detached neighbouring dwellings



Private plant affecting rooms in the same dwelling (the ‘origin’ dwelling)

3 Reference literature

This chapter provides a summary of the noise-related reference literature which acoustics consultants and other building designers refer to when designing dwellings.

With regards to acoustic design guidance and the selection of appropriate noise control targets for new buildings or buildings undergoing a change of use, probably the most referenced source in the UK is BS 8233:1999 *Sound insulation and noise reduction for buildings. Code of practice* [2]. With regards to dwellings, to minimise disturbance from internally generated noise, BS 8233 recommends that:

- *"In houses and flats, services should be kept away from bedrooms.*
- *In flats, avoid locating bedrooms near the lift and circulation areas; less sensitive rooms may be used as buffers. Compatibility between rooms of adjacent dwellings can be ensured by handing and stacking identical dwelling plans.*
- *Any partition separating a WC from a noise sensitive room should have a weighted standardized level difference of at least 38 dB $D_{nT,w}$.*
- *The quietest types of sanitary, heating and plumbing equipment (e.g. WCs, ball valves, refuse chutes etc.) should be used; however their location is more important than their detailed design.*
- *It is good practice to isolate vibration in the heating pipework from the building structure, at least near the pump. This may be achieved by using resilient fixings on pipe runs. Where pipes penetrate walls and floors, air gaps should be sealed to reduce airborne noise transmission in such a way that structure-borne noise is not transmitted: this may be achieved by packing the gap with mineral wool, and sealing the faces with non-hardening mastic.*
- *Ventilation fans and similar equipment should have resilient mountings where structure-borne noise could be a problem.*
- *Care should be taken to position lifts to minimise noise disturbance from the operation of the control gear. Lift doors should operate quietly, and acoustic signals to herald lift arrival should not be audible within dwellings."*

BS 8233 does not provide noise criteria for dwellings specific to building services only. However, it does give noise criteria for 'anonymous noise' (which is reproduced in the following table) and points out that *"occupants will usually tolerate higher levels of anonymous noise, such as that from road traffic, than noise from neighbours which may trigger complex emotional reactions that are disproportionate to the noise level."* This raises the question of whether building services plant can be regarded as 'anonymous noise'. For some noise sources, such as steady broadband air conditioning and ventilation noise, it is likely that in most cases this is regarded as anonymous noise. However, with regards to less steady building services noise sources, it would not be fair to assume that they provoke the same reactions as neighbour noise, such as amplified music, although they can cause disturbance sufficient to cause complaints.

BS 8233: 1999 Extract from Table 5 *Indoor ambient noise levels in spaces when they are unoccupied* and 7.6.1.2 *Design criteria and limits for intrusive external noise*			
Noise type	**Area**	**Good**	**Reasonable**
Anonymous noise limits for reasonable resting/sleeping conditions	Living rooms	≤ 30 dB $L_{Aeq,T}$	≤ 40 dB $L_{Aeq,T}$
	Bedrooms	≤ 30 dB $L_{Aeq,T}$	≤ 35 dB $L_{Aeq,T}$
	Bedrooms - individual noise events at night		≤ 45 dB L_{AFmax}
Noise type	**Area**	**Desirable**	**Upper limit**
Steady noise	Gardens and balconies etc.	≤ 50 dB $L_{Aeq,T}$	≤ 55 dB $L_{Aeq,T}$
RMP Note: Even though this table refers to intrusive external noise, it is frequently referenced for any type of source emitting 'anonymous' noise, including building services noise.			

A key international reference is the World Health Organization's (WHO) Guidelines for Community Noise [3]. By 'community noise' they refer to environmental noise, residential noise or domestic noise. The WHO report lists the main indoor sources of noise as ventilation systems, home appliances and neighbours. The scope of WHO's endeavour to derive guidelines for community noise, was to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in non-industrial environments.

The following table presents the WHO guideline values with respect to adverse health effects in or around dwellings. An adverse effect of noise refers to any temporary or long-term impairment of physical, psychological or social functioning that is associated with noise exposure. **Specific noise limits have been set for each health effect, using the lowest noise level that produces an adverse health effect (i.e. the critical health effect).** WHO advises that if the noise includes a large proportion of low-frequency components, still lower guideline values should be applied.

WHO Guidelines for Community Noise (1999) Community noise is referred to as "environmental noise, residential noise or domestic noise"				
Specific environment	**Critical health effects**	**dB L_{Aeq}**	**Time base (hours)**	**dB L_{AFmax}**
Outdoor living area	Serious annoyance, daytime & evening	55	16	-
	Moderate annoyance, daytime & evening	50	16	-
Dwelling, indoors	Speech intelligibility & moderate annoyance, daytime & evening	35	16	-
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
If the noise includes a large proportion of low-frequency components, still lower guideline limits should be applied.				

BS 8233 does not explicitly state the time period T over which its noise criteria applies. It is usual practice to use the same time base hours set by the WHO report, that is 8 hours for rooms typically used overnight i.e. bedrooms and 16 hours for all other rooms and outdoor areas.

The BS 8233 internal ‘good’ standard and the corresponding WHO bedroom criteria are the same (30 dB L_{Aeq}). However, BS 8233 also gives a 5 dB relaxation to the L_{Aeq} noise limit for a ‘reasonable’ standard in bedrooms. In practice, reducing typical urban external noise levels to 30 dB L_{Aeq} inside is difficult to achieve, unless all windows are closed.

Another difference is that BS 8233 sets the same ‘good’ standard L_{Aeq} noise limit for living rooms and bedrooms, whereas the WHO report sets a 5 dB more relaxed L_{Aeq} noise limit for rooms other than bedrooms. This may be because the WHO report regards the main objectives in rooms other than bedrooms, to be speech intelligibility and limiting the onset of ‘moderate annoyance’ whereas BS 8233 is concerned with ‘resting/sleeping conditions’ in both living rooms and bedrooms.

The BS 8233 and WHO criteria can be regarded as the same for outdoor living areas; that is 50 dB L_{Aeq} for ‘desirable’ (BS 8233) or onset of ‘moderate annoyance’ (WHO) and 55 dB L_{Aeq} for ‘upper limit’ (BS 8233) or onset of ‘serious annoyance’ (WHO). In practice, planning permission for a new dwelling is sometimes granted in environments with daytime noise levels as high as 71 dB L_{Aeq}. In which case the BS 8233/WHO noise criteria would be disproportionately low.

Another well known reference source is the Building Research Establishment (BRE) & Construction Industry Research and Information Association (CIRIA) *Sound Control for Homes* [4] which suggests noise limits specific to mechanical services (unlike BS 8233 and WHO), as reproduced in the following table. This book recommends that these limits apply when the equipment is in normal use and that the sound should contain no distinguishable tonal or impulsive characteristics.

BRE/CIRIA Sound Control for Homes		
Suggested design background noise level arising from mechanical services*		
Room classification		**dB(A)**
Sensitive rooms:	Bedroom	< 30
	Living room	< 35
	Dining room	< 35
Less sensitive areas:	Kitchen, bathroom, utility room, WC, internal and communal circulation areas	< 45
*Clarification from the author, John Miller: Mechanical services noise is, or should be, steady. It therefore does not matter what noise index you use to measure it. From a practical point of view, L_{A90} can be a convenient measurement index, as it excludes spurious intermittent noises which can occur when conducting commissioning tests in a completed building.		

A direct comparison of the BRE/CIRIA criteria is not appropriate since the BS 8233 and WHO criteria apply to all sources of noise, whereas the BRE/CIRIA criteria only apply to mechanical services. However, we may infer that BRE/CIRIA do not see the need to limit mechanical services noise in bedrooms and living/dining rooms any lower than the BS 8233 and WHO criteria for all types of intrusive noise. This is presumably because the WHO report states that adverse health effects should not normally occur below these levels.

The BRE/CIRIA criteria presents a further room classification of 'less-sensitive areas' recognising that a 10 dB relaxation on the living/dining room noise limit is tolerable in areas such as the kitchen and bathroom.

The Chartered Institution of Building Services Engineers (CIBSE) has recently updated their long-standing reference guide on environmental design of building services [5]. The Acoustic Environment section recommends "Reasonable design limits to minimise annoyance from broadband continuous noise from building services installations" as follows:

CIBSE Guide A Environmental Design	
Suggested maximum permissible background noise levels generated by building services installations	
Dwellings (urban):	Noise Rating (NR)
Bedroom	< NR25
Living room	< NR30
Corrections to [measured] noise rating for certain types of noise:	
Type of noise:	NR correction
Pure tone easily perceptible	+5
Impulsive and/or intermittent	+3

Noise Ratings (NR) are explained in Annex A. The relationship between NR and an A-weighted parameter is not constant because it depends upon the spectral characteristics of the noise. However, for ordinary building services noise, the dB(A) level is usually between 4 and 8 dB greater than the corresponding NR. The range of possible L_{Aeq} values for the CIBSE NR noise limits (from 63 Hz to 4 kHz) are as follows:

NR25	min	25 dB L_{Aeq}	NR30	min	30 dB L_{Aeq}
	max	35 dB L_{Aeq}		max	40 dB L_{Aeq}

It can be seen that the NR25 noise limit for bedrooms is potentially 5 dB more or less stringent than the BS 8233/WHO noise criteria.

CIBSE discusses the merits of NR (and similar curves) as opposed to an A-weighted parameter:

> *"The dBA measure is often used as an indicator of human subjective reactions to noise across the full range of frequencies audible to humans. This index is simple to measure using a sound level meter incorporating an A-weighting network. In addition, the measured noise spectrum can be compared with reference curves such as the NR or NC curves which aid identification of any tonal frequency components. This is the usual method of assessment for mechanical services installations.*
>
> *Noise rating (NR) curves are commonly used in Europe for specifying noise levels from mechanical services in order to control the character of the noise. [..] More recent developments in North America have lead to the introduction of room criterion (RC) curves.*
>
> *RC curves provide a more detailed description of the noise than is available from NR. In addition, room criteria are more prescriptive at low frequencies than NR. At 31.5 Hz, permitted NR35 levels are 19 dB higher than RC35 levels. A noise which follows the NR curve will be unpleasantly 'rumbly' compared with the neutral sound of a noise that follows the RC curve. Therefore NR continues to be adequate only where low frequency noise levels are well below the NR limit. The potential drawback of NRs is that they permit unacceptable noises that would have been rejected if RC had been applied."*

It should be noted that an NR compliance assessment takes longer than an A-weighted assessment, because most sound level meters do not automatically calculate the NR level for a measured noise spectrum. However, as the NR curves are a series of octave band limits, it is a more effective objective tool for penalising tonal noise problems. As raised in the above CIBSE discussion, NR is not robust enough to tackle all low frequency noise problems.

4 Existing legislation & guidance

This chapter provides a summary of the British & European building regulations which make reference to controlling building services noise in new dwellings.

Scottish planning conditions

Scottish local authorities usually refer to Planning Advice Note 56 ‘Planning and Noise’ (PAN56) [6] when assessing noise impact on or arising from potential developments. The PAN56 Noise Exposure Categories (NEC) is commonly used to assess the impact of transportation noise on proposed residential development. However, specific advice on setting standards for industrial or commercial type noise is limited to references to BS 4142 [7] and BS 8233 (as discussed in Chapter 3).

In our experience, not all local authorities impose a specific condition with regards to building services noise; however, many do and a typical city council planning condition could be one or more of the following:

> *“The design and installation of any plant, machinery or equipment shall be such that any associated noise complies with NR25 when measured within any nearby living apartment, and no structure borne vibration is perceptible within any nearby living apartment.*
>
> *The development shall be so designed and constructed to ensure that any noise from the electrical substation complies with NR20 when measured within any living apartment measured on an open window standard.*
>
> *Design, installation and operation of all lifts shall be such that any associated noise complies with NR20 when measured within any living apartment.*
>
> *Where any living apartment requires its windows to be closed in order to achieve a satisfactory internal noise level, an alternative means of providing fresh air ventilation shall be provided. The internal noise levels associated with any mechanical units and associated ductwork shall not exceed NR20. The ventilation system shall be designed to ensure that noise from external sources is not conducted into any habitable room.”*

It would appear that local authorities tend to use NR due to the benefit in minimising the risk of tonal noise problems. The range of possible L_{Aeq} values for the above NR noise limits (from 63 Hz to 4 kHz) are as follows:

NR20	min	20 dB L_{Aeq}	NR25	min	25 dB L_{Aeq}
	max	30 dB L_{Aeq}		max	35 dB L_{Aeq}

It can be seen that the NR20 noise limit is potentially 10 dB more stringent than the BS 8233/WHO bedroom noise criteria.

Building Regulations (Scotland)

The building regulations set functional standards, one of which is Standard 5.1 relating to noise. Part of the standard relates to sound insulation of separating walls and floors in order to provide protection between dwellings. Standard 5.1 can be met by using 'specified constructions' or by sound insulation testing to demonstrate that the recommended performance values have been met [8]. However, neither approach may be sufficient to attenuate services noise to an acceptable level inside neighbouring dwellings. One reason for this is that there is a wide range of services noise emission levels, i.e. quieter services may be attenuated sufficiently by Standard 5.1 compliant constructions but noisier services would not be. Another reason is that services noise is often manifested as a result of vibrational energy input to the building structure which has been transmitted as structure-borne noise. For example, whilst a separating wall type may provide a mean of 53 dB $D_{nT,w}$ airborne sound insulation, a poorly isolated pump located adjacent to the wall, producing only low level airborne noise, could still cause significant disturbance due to its vibrational energy causing structure-borne noise transmission.

Building Regulations (England and Wales)

There are no services noise performance standards in the series of approved documents with respect to the Building Regulations 2000 for England and Wales. However, in Approved Document E *Resistance to the passage of sound* [9], there is a mass per unit area requirement given for walls separating a refuse chute.

Services noise is mentioned in Approved Document F *Means of ventilation* [10]:

> *"Section 0: General guidance*
> *Noise from ventilation systems*
> *0.32 Noise generated by ventilation fans (which may propagate through ducts and ductwork) can disturb the occupants of the building and so discourage their use. Therefore, the designer should consider minimising noise by careful design and the specification of quieter products. Noise from the ventilation system may also disturb people outside the building, so externally emitted noise levels should also be considered."*

In terms of environmental noise ingress via building services, Approved Document F gives the following warning:

> *"Noisy locations*
> *0.31 In noisy areas it may be appropriate to use either sound-attenuating background ventilators or mechanical ventilation solutions, depending on the noise level and any planning conditions."*

Similar advice appears in Approved Document J *Combustion appliances and fuel storage systems* [11]:

> *"Section 1: Provisions which apply generally to combustion installations*
> *1.10 Permanently open air vents should be non-adjustable, sized to admit sufficient air for the purpose intended and positioned where they are unlikely to become blocked. Ventilators should be installed so that building occupants are not provoked into sealing them against draughts or noise. [..]*

1.16 [..] In noisy areas, it may be necessary to install proprietary noise attenuated ventilators to limit the entry of noise into the building."

Code for Sustainable Homes

The Code for Sustainable Homes by the Department for Communities and Local Government describes voluntary standards for certain aspects of design and construction to limit environmental impact of housing. From the Technical Guide [12] published in March 2007, Category 1 *Energy and Carbon Dioxide Emissions* states that noise must form part of the feasibility study to establish the most appropriate Zero or Low Carbon (ZLC) energy technology for a building or development. The other reference to noise is in Category 7 *Health & Wellbeing*:

"BS 8233:1999 Sound insulation and noise reduction for buildings – Code of practice – sets out guidance on good acoustic planning in section 7.6.1.3. The following principles are recommended for minimising disruption from noise in dwellings (see the standard for full details):

1. *Keep services away from bedrooms in houses and flats;*
2. *Keep stairs, lifts and circulation areas in apartment buildings away from sensitive rooms such as bedrooms;*
3. *Corridors in apartment buildings should have acoustically absorbent ceilings. Carpets can also help to reduce disturbance in adjacent apartments;*
4. *Separating walls between bathrooms and sensitive areas should be designed to minimise acoustic transmissions;*
5. *Isolate pipework and ductwork from the building structure to avoid vibration being transmitted and all penetrations of services should be sealed."*

Noise Insulation Regulations

The Noise Insulation Regulations 1975 for England & Wales [13] and the Noise Insulation (Scotland) Regulations 1975 [14] provide for the insulation of buildings against noise caused or expected to be caused by traffic using certain new highways and certain altered highways and by certain highway works. They impose a duty on highway authorities to carry out noise insulation work or to make a grant available. The noise insulation work includes the provision and installation of a sound attenuating mechanical ventilator unit so that window(s) need not be open for ventilation. The Regulations state that the **self-noise of the ventilator unit** shall not exceed 35 dB(A) or 40 dB(A) at its maximum ventilation rate, when measured at any point not nearer than 1 metre to the unit or to any of the room surfaces and normalised by -10log(10/A) where A is the measured sound absorption of the room.

<u>Building Regulations in European Countries</u>

As a starting point, this chapter uses the information provided by *Building Regulations in Europe* [15] which is the result of a research project initiated and financed by the Dutch Ministry of Housing, Physical Planning and Environment, to compare the systems of building regulations and their technical requirements in the Netherlands, England & Wales, Belgium, Denmark, France, Germany, Norway and Sweden (current in 2000-2002). The intention was to inform the development of the Bouwbesluit, the Dutch Building Decree. We have sought to check whether any of these requirements have been amended since publication of the aforementioned book. Any information we have gathered is included in this chapter.

A summary of the services noise limits for each country are given in the following tables, along with a discussion highlighting aspects which appear to be useful and pragmatic and those that may be less worthwhile or more problematic to implement. Some countries do not use the L_{Aeq} noise parameter. However, most of their parameters can be considered to be approximately equivalent to L_{Aeq} (other than L_{In} L_{Amax} L_{AFmax} or L_{pAFmax}). The noise parameters are listed in the glossary at Annex A.

The Netherlands			
Types of installation	**Situation**	**Requirement**	
Flush toilets, taps, mechanical ventilation systems, hot water equipment, equipment to increase water pressure, lifts.	Habitable area of user function on adjacent plot. Non-shared habitable area of another living function on the same plot.	Characteristic sound level:	
		New build	≤ 30 dB $L_{I;A}$
		Adaptation or extension of existing buildings	≤ 40 dB $L_{I;A}$
Reproduced from Appendix 4 of *Building Regulations in Europe* [15]			

With regards to residential services noise, the Dutch Building Decree stipulates limits for:

- services noise affecting a communal or private habitable space in a neighbouring residential building, and

- services noise affecting a private habitable space of another dwelling in the same building.

It does not stipulate limits for services noise affecting the ‘origin’ dwelling or communal space of the same building.

The Netherlands allows a 10 dB relaxation for conversions and extensions, to allow for the difficulty in quantifying flanking transmission in existing buildings. Presumably this relaxed noise limit only applies to neighbouring dwellings in the same plot, rather than detached residential buildings.

We understand from Dr F. Meijer at the Technical University of Delft, that there have been no amendments to this aspect of the Dutch Building Decree.

Belgium			
Types of installation	**Situation**	**Requirement**	
External noise. Noise within the building but external to the room to be protected.	Living spaces in:	For existing background noise:	For installation noise ≥ 27 dB L_{Aeq}
	Category 1	≤ 30 dB L_{Aeq}	difference between installation noise and background noise must be ≤ 6 dB
	Category 2	≤ 35 dB L_{Aeq}	
	Category 3	≤ 40 dB L_{Aeq}	
	Category 4	≤ 45 dB L_{Aeq}	
	Bedrooms in:	For existing background noise:	For installation noise ≥ 27 dB L_{Aeq}
	Category 1	≤ 30 dB L_{Aeq}	difference between installation noise and background noise must be ≤ 3 dB
	Category 2	≤ 30 dB L_{Aeq}	
	Category 3	≤ 35 dB L_{Aeq}	
	Category 4	≤ 40 dB L_{Aeq}	
	Toilet Bathroom Kitchen	≤ NR 35 (an increase of 5 dB when the equipment starts or stops operation is acceptable)	
Category 1 Rural or suburban residential areas Category 2 Urban residential areas Category 3 Areas affected by light industries and housing in commercial areas Category 4 Town centres, areas affected by heavy industries and areas within 5 km of an airport			
Reproduced from Appendix 4 of *Building Regulations in Europe* [15]			

It would appear that Belgium goes further than the Dutch Building Decree, by protecting the specified rooms within the origin dwelling (apart from the room the equipment is serving) as well as specified rooms within neighbouring dwellings within the same building and neighbouring residential buildings.

We have contacted Professor Vermeir at the Katholieke Universiteit in Leuven to seek clarification regarding the requirement column in the preceding table. We feel it is almost certainly the intention that the installation noise is no more than 3 or 6 dB higher than the background noise level.

The Belgian requirements are related to planning zones, with different levels that take account of the fact that residents are likely to be more tolerant of services noise where the new development will be in a relatively high ambient noise environment. For large developments introduced to a rural area, where the original ambient noise level was very low, the development itself will increase the ambient noise level due to new roads, more reflective surfaces etc, so the services noise limits would presumably be based on the new background noise level, otherwise they could be unnecessarily low.

The Belgian system recognises that tolerance to services noise will be more in living rooms than it is in bedrooms and more tolerant still in rooms of short-term occupancy, like the toilet, bathroom and kitchen. Services noise in these short-term occupancy rooms is limited to NR35 regardless of the development area category. A noise limit regardless of the external noise ingress is sensible since these types of rooms will be less influenced by external noise than the habitable rooms in the same dwelling.

It is recognised that short-term occupancy rooms will not be unduly affected by 5 dB peaks above the noise limit, such as when the services operation starts or stops. This would seem a pragmatic relaxation. However, checking compliance could be putting an additional burden on the assessor who would have to make three discrete measurements: (1) start (2) steady-state and (3) end. In practice, it would be easier if the criteria allowed the assessor to take one measurement of the complete noise envelope and check that the overall L_{eq} spectrum does not exceed NR35 and the L_{max} spectrum does not exceed NR40.

It is interesting to note that although the noise limit for short-term occupancy rooms is less stringent, it could be argued that there is more effort involved in the design, since the services noise airborne propagation and structure-borne transmission would have to be predicted in terms of octave bands. Also, to check compliance could take longer, since most sound level meters (other than perhaps the top range of the latest generation) do not give the NR value - an assessor would either have to compare each octave band result with a table of NR spectra or plot the octave band results on to a set of NR curves.

The Belgian system recognises that the difference method (which is also employed by BS 4142 [7]) must have a starting point, i.e. that the noise limits apply only when services noise exceeds 27 dB L_{Aeq}. This ensures that services noise which is low level is permitted, even if it is more than 3 or 6 dB higher than the background noise (because of an exceptionally quiet environment).

With regards to the background noise level used to check compliance, we sought clarification from Professor Vermeir, but at the time of finalising this report, had received no response to the following queries:

Is it the background noise level measured before the dwelling was built (corrected to given an internal level)? If so, is this measurement generally an L_{Aeq} or L_{A90} level? Over what time period is the measurement?

or is it the background noise level measured inside the completed room, with all building services operation suspended? If so, is this measurement generally an L_{Aeq} or L_{A90} level? Are the windows open or closed? Over what time period is the measurement?

or is it the maximum allowable background noise level for the relevant category? e.g. 30 dB L_{Aeq} for living rooms in Category 1, giving an installation noise limit of 36 dB L_{Aeq}.

Denmark		
Types of installation	**Situation**	**Requirement**
	Small buildings:	
Drainage, ventilation or heating equipment, waste disposal units etc.	Habitable rooms, kitchens	≤ 30 dB L_{Aeq} ≤ 25 dB L_{Aeq} for momentary sounds such as motors starting or stopping; noise with a pure tone such as whistle from a fan
Utility water equipment, installations for operation of windows, sunscreens etc.	Neighbouring houses	≤ 30 dB L_{Aeq}
	Multi-storey domestic buildings:	
Drainage and utility water equipment, lifts, ventilation and heating systems, macerators, equipment in common service rooms e.g. laundry-rooms, kitchens; excludes noise from water installation in utility dwelling itself.	Habitable rooms, kitchens	≤ 30 dB L_{Aeq}
Installations in commercial units in domestic buildings.	Habitable rooms	≤ 30 dB L_{Aeq}
Heating and ventilation systems, mechanical refuse collection systems etc.	At windows, in recreation areas (balconies, roof terraces, conservatories etc.)	≤ 40 dB L_{Aeq}
Reproduced from Appendix 4 of *Building Regulations in Europe* [15]		

It would appear that Denmark also goes further than the Dutch Building Decree, by protecting rooms within the origin dwelling, as well as neighbouring dwellings within the same building, neighbouring residential buildings and outdoors (at windows & private recreation areas). No distinction is made between living rooms and bedrooms.

The criteria for small buildings and multi-storey domestic buildings are separated, presumably to identify the installations which could be noise sources in each type of building, since the steady-state non-tonal internal noise limits are the same regardless. There does not seem much to be gained from this approach, since it could lead to confusion or even misuse; for example, there is just as much likelihood of ventilation noise impacting on neighbouring houses as for habitable rooms in the same building. Also, listing installations in this way may not be very future-proof; for example, amendments would have to be drafted to include new technologies such as low and zero carbon energy sources.

It is not obvious why an additional reduced noise limit is applicable for momentary or tonal sounds in houses but not flats. Unlike Belgium, Denmark has decided that start and stop noise could be more annoying than the steady-state noise and so the noise limit is reduced by 5 dB to minimise this risk. The Danish do not explicitly say that impulsive noise character as well as tonality should be subject to the reduced noise limit (since this is different from 'momentary' noise before steady-state operation is established).

As for the Belgian requirements, there is the difficulty of acquiring a reliable L_{Aeq} measurement for a momentary sound.

France		
Types of installation	**Situation**	**Requirement**
Heating or air-conditioning unit.	Principal rooms	≤ 35 dB L_{nAT}
	Kitchens	≤ 50 dB L_{nAT}
Heating appliance unit operating at minimal power.	Principal room open plan with kitchen	≤ 40 dB L_{nAT}
Mechanical ventilation installation at minimum setting.	Principal rooms	≤ 30 dB L_{nAT}
	Kitchens of each dwelling	≤ 35 dB L_{nAT}
Any equipment unit operating normally in a dwelling.	Principal rooms in other dwellings	≤ 30 dB L_{nAT}
	Kitchens in other dwellings	≤ 35 dB L_{nAT}
Common equipment such as lifts, heating plant, transformers, pumps, soil pipes.	Principal rooms	≤ 30 dB L_{nAT}
	Kitchens	≤ 35 dB L_{nAT}
Reproduced from Appendix 4 of *Building Regulations in Europe* [15] and amended for clarification		

We can confirm that these requirements have not been amended since 30 June 1999.

France goes further than the Dutch Building Decree, that is protecting principal rooms and kitchens within the origin dwelling, as well as neighbouring dwellings within the same building and neighbouring residential buildings. No distinction is made between living rooms and bedrooms.

The noise limits for equipment serving communal space appear to be for each individual noise source (not the total possible noise from all equipment). This would imply that two equal source levels operating simultaneously could exceed the noise limit by 3 dB and three source levels by 5 dB etc.

Like Denmark, France lists specific types of services noise, rather than using a comprehensive description which would encompass old, new and future technologies.

<table>
<tr><th colspan="3">Germany</th></tr>
<tr><th>Types of installation</th><th>Situation</th><th>Requirement</th></tr>
<tr><td>Water and waste water installations.
Noise from business activities, plants.</td><td>Living room, bedroom</td><td>≤ 35 dB L_{In}
≤ 30 dB L_{AFmax}
≤ 35 dB L_r (06:00-22:00) +10 dB(A) for brief peaks
≤ 25 dB L_r (22:00-06:00) +10 dB(A) for brief peaks</td></tr>
<tr><td colspan="3">Reproduced from Appendix 4 of Building Regulations in Europe [15]</td></tr>
</table>

The German Building Ordinance refers to the DIN 4109 series of standards. We have reviewed DIN 4109-1 which was published as a draft standard in October 2006 (i.e. since *Building Regulations in Europe* was written) and our interpretation is as follows:

<table>
<tr><th colspan="5">Germany</th></tr>
<tr><th>Types of installation</th><th>Situation</th><th colspan="3">Requirement</th></tr>
<tr><td>Mains water supply and sewerage (i.e. external to dwellings).</td><td>Living room, bedroom</td><td colspan="3">≤ 30 dB L_{AFmax}</td></tr>
<tr><td>Shared, permanently installed technical services (i.e. external to dwellings).</td><td>Living room, bedroom</td><td colspan="3">≤ 30 dB L_{AFmax}

+5 dB relaxation for ventilation noise if it is steady without noticeable peaks/characteristics.</td></tr>
<tr><td>Noise from commercial, retail plant.</td><td>Living room, bedroom</td><td colspan="3">≤ 35 dB L_r and ≤ 45 dB L_{AFmax} (06:00-22:00)
≤ 25 dB L_r and ≤ 35 dB L_{AFmax} (22:00-06:00)</td></tr>
<tr><td>Private technical services (i.e. internal to dwellings), except water installations.</td><td>Living room, bedroom</td><td colspan="3">≤ 30 dB L_{AFmax}

+5 dB relaxation for ventilation noise if it is steady without noticeable peaks/characteristics.</td></tr>
<tr><td rowspan="4">Water installations internal to dwellings.</td><td rowspan="4">Living room, bedroom</td><td rowspan="2">Standard Equipment</td><td>Class I</td><td>≤ 20 dB(A)</td></tr>
<tr><td>Class II</td><td>≤ 30 dB(A)</td></tr>
<tr><td rowspan="2">Optional Extras</td><td>Class I</td><td>≤ 15 dB(A)</td></tr>
<tr><td>Class II</td><td>≤ 25 dB(A)</td></tr>
<tr><td colspan="5">These noise limits do not apply to brief peaks caused by using the equipment, e.g. starting, stopping, adjusting etc.</td></tr>
<tr><td colspan="5">Class I & II water installations are defined in ISO 3822 according to flow rate and pressure.</td></tr>
<tr><td colspan="5">From §10 of draft DIN 4109-1:2006-10</td></tr>
</table>

Like Denmark & France, Germany does not set different noise limits for living rooms and bedrooms.

The L_{AFmax} limit (with or without the 5 dB relaxation for steady ventilation noise) appears to be stringent compared to the WHO report [3] which identifies 45 dB L_{AFmax} as the point at which sleep disturbance can occur. However, the draft DIN 4109-1 states that the assessment does not include the brief peaks caused by starting, stopping or adjusting the equipment. This explains how such a low L_{AFmax} could be practicable, but begs the question as to why an L_{AFmax} parameter is used at all if not to control the brief peak noise levels from events such as starting and stopping the equipment. It would suggest that there is no limit on noise from such events, even though, in our experience, it is often these brief peaks that cause irritation, such as the impulsive sound of a lift starting or stopping. We have contacted members of the German Society for Acoustics to clarify this.

Norway		
Types of installation	**Situation**	**Requirement**
Lifts, escalators, fans, sanitary appliances, air conditioning plants, installations for service or commercial purposes: washing machines (common laundry rooms), refrigeration machines (shops), production machinery (industry) etc. Noise from use and running of indoor car parks.	Bedrooms, rooms for occupation (excluding storage rooms, toilets, bathrooms, hallways and corridors).	≤ 30 dB $L_{Aeq,24h}$ ≤ 32 dB L_{Amax}
	Also, limits on noise nuisance from equipment to outdoor areas intended for recreation or play.	≤ 40 dB L_{Amax}
Reproduced from Appendix 4 of *Building Regulations in Europe* [15]		

Norway is unusual in setting a noise limit for outdoor areas (beyond Denmark's requirements for windows, balconies etc in flats); it is not clear whether this includes communal as well as private outdoor areas.

The reference to indoor car parks is interesting. Whilst it may be practical to meet noise limits for known noise sources associated with 'running' a car park e.g. roller shutter doors, extract fans etc, complying with these noise limits for any possible vehicle using the car park is unrealistic. The acoustician can only design separating contractions sufficient to attenuate noise from the majority of vehicles likely to use the car park.

As for Germany, the Norwegian L_{Amax} limits appear to be overly stringent, compared to the scientific basis of the WHO report [3].

Sweden			
Types of installation	**Situation**	**Requirement**	
Building services.	Sounds not from within same dwelling:	Sound duration:	
	Bedrooms, living rooms in non-residential premises	long	≤ 30 dB L_{pA}
		short	≤ 35 dB L_{pAFmax}
	Kitchens	long	≤ 35 dB L_{pA}
		short	≤ 40 dB L_{pAFmax}
Note: Sounds of short duration include sound due to pressure pulses or flow of water in water supply and drainage installations, impulse sound due to the starting and stopping of lifts; sounds of long duration include sound from ventilation plants, refrigerator compressors, heat pumps.			
Reproduced from Appendix 4 of *Building Regulations in Europe* [15]			

We assume that the reference to bedrooms & living rooms applies to dwellings as well as ‘non-residential premises’ such as hotels, hospitals etc.

The use of L_{AFmax} to quantify “short duration sounds” seems to be a more logical approach, if it can be taken from a single measurement of the complete noise source envelope.

<u>Typical practice elsewhere</u>

There are no relevant services noise requirements forming part of building regulations in the USA, Canada, Australia or New Zealand.

From a conversation with a Californian acoustician it would seem that they are primarily guided by the publications of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and their own experience of good practice.

The Association of Australian Acoustical Consultants (AAAC) are aware of the risk of adverse feedback from new residents and have compiled their own rating system to rank the acoustical quality of apartments/townhouses and promote better standards of acoustical quality. An AAAC Rating Certificate can only be issued by an AAAC member firm.

It deals with the major issues, including the intrusion of external noise, noise generated by building services and appliances and noise transfer between apartments or townhouses. It is intended to complement rather than compete with the established statutory or advisory codes. The current rating system for building services noise is shown in the following table.

Australia							
Association of Australian Acoustical Consultants (AAAC) Acoustical Star Ratings Version 9.4 May 2005 downloadable from www.aaac.org.au							
Types of installation	**Situation**	**Requirement**	**2 star**	**3 star**	**4 star**	**5 star**	**6 star**
Internal building services and appliances	Bedrooms	continuous noise dB $L_{Aeq\ adj}$ ≤	36	35	32	30	27
		intermittent noise dB $_{ave}$ L_{Amax} ≤	45	40	35	30	27
	Other habitable rooms including open kitchens	continuous noise dB $L_{Aeq\ adj}$ ≤	41	40	35	30	27
		intermittent noise dB $_{ave}$ L_{Amax} ≤	50	45	40	35	32
	Wet areas including bathrooms, en-suites and laundries	continuous noise dB $L_{Aeq\ adj}$ ≤	55	50	45	42	40
		intermittent noise dB $_{ave}$ L_{Amax} ≤	60	55	48	42	40
Measurements are made at relevant positions, but no closer than 1.5 m from the noise source.							
Noise with tonal or impulsive characteristics have a penalty adjustment (adj). If these characteristics are clearly audible a 5 dB(A) penalty shall be applied. If the characteristics are just audible then a 2 dB(A) penalty shall be applied.							

It would seem that the AAAC rating system considers services noise within the origin dwelling, as well as neighbouring dwellings in the same building and neighbouring residential buildings.

In our opinion, the 2 and 3 star L_{Aeq} performance requirements are poor, whereas the 4, 5 and 6 star L_{Amax} limits are overly stringent compared to the WHO guidance on sleep disturbance and annoyance.

The application of a tonal/impulsive penalty is a familiar approach (cf. BS 4142 [7]) and such noise sources can usually be identified at the design stage. However, the AAAC rating system is clearly based on pre-completion noise measurements since they grade the penalty depending on the audibility of the characteristic. The difference between “clearly audible” and “just audible” could be open to question, unless there is a more objective definition.

It is interesting that they have applied two different parameters depending on whether the noise is continuous or intermittent. However, it is not clear why both parameters could not be applied to both types of noise source. For instance, it would be interesting to know whether it’s possible for an intermittent noise in a bedroom to achieve a 3 star rating (≤ 40 dB L_{Amax}) but exceed 35 dB L_{Aeq} (equivalent only to a 2 star rating).

5 Design criteria for rooms for sleeping

This chapter presents building services noise criteria for the design of some types of buildings which include rooms for sleeping. The type and scale of building services plant may differ from that of dwellings, but the general nature of noise and the design intent are similar.

Hotels

Successful hotel chains have recognised that good acoustics, privacy and noise control are important in providing their guests with a restful stay and encouraging them to choose their hotel again over their competitors.

The major hotel brands issue a technical brief to the architect/developer, which normally includes requirements for protection from external noise, internal sound insulation, room acoustical quality, and hotel-generated building services noise. A summary of building services noise limits from a selection of recent RMP hotel projects is presented below.

Hotel bedrooms				
Hotel brand	**Types of installation**		**Requirement**	
A	General services equipment in the building		L_{nAT} (where T_r = 0.5s)	≤ 25 dB(A)
	Terminal apparatus for bedroom heating-air conditioning e.g. fan coil unit	1st speed (min speed)		≤ 28 dB(A)
		2nd speed		≤ 31 dB(A)
		3rd speed (max speed)		≤ 37 dB(A)
	Sanitary equipment in the bathroom of the same room			≤ 35 dB(A)
	Sanitary equipment in service duct, bathroom and WC in the adjacent room			≤ 30 dB(A)
B	Mechanical engineering services		Not specified	≤ NC30
C	Air conditioning units		Lowest setting	≤ 36 dB(A)
			Rated duty	≤ 44 dB(A)
D	Building services		L_{eq}	≤ NR 25

If we assume that L_{nAT} is roughly equivalent to L_{Aeq} measured in a furnished room (i.e. where the reverberation time T_r is ~ 0.5 seconds) then Hotel Brand A sets a 5 dB more onerous noise target for 'general services equipment' compared to the reference literature bedroom criteria discussed in Chapter 3. This may be a reflection of the fact that hotel guests do not usually have time to become accustomed to noise sources outwith their control. However, Hotel Brand A recognises that for services equipment under their control (i.e. the air-conditioning unit and bathroom in the same room), the noise can be up to 12 dB louder than 'general services equipment'. Similarly, Hotel Brand C sets noise limits for the air-conditioning unit within the same room which are up to 14 dB higher than the bedroom noise limits (from all services) given in the reference literature discussed in Chapter 3.

The noise criteria for Hotel Brands B and D are in terms of octave band noise limits (from the NC and NR sets of curves) so a direct comparison with the reference literature in Chapter 3 is not appropriate. Depending on the frequency content, the Hotel Brand B noise criteria could equate to any A-weighted level between approximately 30 dB L_{Aeq} and 40 dB L_{Aeq}. Depending on the frequency content, the Hotel Brand D noise criteria could equate to any A-weighted level between approximately 25 dB L_{Aeq} and 35 dB L_{Aeq}.

Hospitals

The Engineering Health Technical Memoranda series (HTM) by the Estates & Facilities Division of the Department of Health, gives guidance on the design, installation and operation of specialised building and engineering technology used in the delivery of heath care. The draft HTM 08-01 (which is due to replace HTM 2045) sets out minimum recommended noise and vibration criteria and makes the following comment:

"Good acoustic conditions improve patient privacy and dignity, and essential sleep patterns, and there is growing evidence that such conditions are an essential part of the healing process."

The following is an extract from §2.3.1 of the draft HTM 08-01 which was released for consultation through the Institute of Acoustics in November 2006.

"The criteria given below refer to the total noise from the mechanical and electrical services (including drainage under normal rainfall conditions), excluding medical equipment. The limits should be measured as L_{90}."

Table 2: Target criteria for internal noise from mechanical and electrical services

Area Type	Example	Noise from mechanical and electrical services
Ward areas, sleeping areas	Single bed ward, multi-bed ward, on-call and recovery rooms, relatives overnight stay	NR 30

This noise limit is in terms of octave band noise limits (from the NR set of curves) so a direct comparison with the reference literature in Chapter 3 is not appropriate. Depending on the frequency content, NR 30 could equate to any A-weighted level between approximately 30 dB L_{Aeq} and 40 dB L_{Aeq}.

6 Recommended criteria

The input, transmission and radiation of services noise in a building is complex. Services noise nuisance commonly occurs because the relevant expertise has not been commissioned to predict and mitigate this noise at the design phase. Even if the sound insulation of the separating wall and floor constructions are in line with Section 5 of the Technical Handbooks [8], this is not necessarily sufficient to attenuate services noise to an acceptable level inside neighbouring dwellings. One reason for this is that there is a wide range of services noise emission levels, i.e. quieter services may be attenuated sufficiently by Section 5 constructions but noisier services would not be. Another reason is that services noise is often manifested as a result of vibrational energy input to the building structure which has been transmitted as structure-borne noise. For example, whilst a separating wall and associated flanking elements may provide 53 dB $D_{nT,w}$ airborne sound insulation, a poorly isolated pump located adjacent to the wall, producing only low level airborne noise, could still cause significant disturbance due to its vibrational energy causing structure-borne noise transmission. Structure-borne noise transmission should not be confused with airborne flanking noise transmission, as a well detailed flanking design can still exhibit structure-borne noise transmission.

The most effective way to avoid services noise problems starts with judicious location and then by specifying practicable noise and/or vibration limits for each piece of services equipment. Any residual noise can be reduced by enclosing the equipment, specifying an appropriate mounting and/or enhancing the sound insulation of the separating constructions.

From the review documented in preceding chapters and our experience of successful and practical criteria, we offer to SBSA the following noise criteria to be considered for adoption in the building regulations:

<table>
<tr><th colspan="3">RMP suggested building services noise criteria</th></tr>
<tr><td colspan="3">All building services affecting neighbouring dwellings and all building services installations common to multiple dwellings (e.g. lifts) affecting them or neighbouring dwellings</td></tr>
<tr><td colspan="2">Bedrooms</td><td>≤ 30 dB L_{Aeq}
≤ 45 dB L_{AFmax}</td></tr>
<tr><td colspan="2">Living rooms</td><td>≤ 35 dB L_{Aeq}</td></tr>
<tr><td colspan="2">Less sensitive rooms:
kitchen, toilet, bathroom</td><td>≤ 45 dB L_{Aeq}</td></tr>
<tr><td>Noise character</td><td colspan="2">Impulsive and/or tonal penalty of 5 dB to the L_{Aeq} limit only</td></tr>
<tr><td rowspan="3">Measurement period</td><td>Continuous noise</td><td>≥ 30 seconds</td></tr>
<tr><td>Non-steady noise
e.g. lift movement</td><td>Representative of complete cycle</td></tr>
<tr><td>Intermittent noise</td><td>Measure during ON or HIGH setting</td></tr>
<tr><td>Frequency range</td><td colspan="2">63 Hz to 4 kHz minimum</td></tr>
</table>

We offer the following justification behind our suggested noise criteria:

Scope: We suggest that protection of neighbouring dwellings (from private and shared building services) is the minimum scope of criteria that the Building Regulations should adopt; the issues with regards to expanding it to include the origin dwellings are discussed later.

Bedrooms: This noise limit is based on the solid scientific knowledge behind the WHO report [3] and does not deviate from the criteria in the BS 8233 Code of Practice [2], which is well established in the UK building design industry.

Living rooms: This noise limit is in accordance with the WHO report and is between the 'good' and 'reasonable' standards from the BS 8233 Code of Practice.

Less sensitive rooms: In the absence of relevant WHO or BS 8233 criteria, this noise limit is in accordance with the BRE/CIRIA guidance [4]. We agree that a 10 dB relaxation for these types of rooms is reasonable (compared to the living room standard), since good 'resting' conditions are less important here.

Parameters: The noise limits employ L_{Aeq} and L_{AFmax} parameters instead of NR curves. This is because, in our opinion, the subjective response to noise is best represented by a fixed A-weighted level rather than an NR curve (corresponding to a range of possible A-weighted levels). The popularity of A-weighted parameters is also due to the simplicity of assessment, since all sound level meters display A-weighted levels but NR assessment often involves 'manual' analysis of each octave band, e.g. by plotting the measured octave band levels against a set of NR curves. Rather than introducing the complexity of using both types of parameter, we believe that tonal problems will be sufficiently dealt with by the noise character penalty.

Noise character: This penalty is in accordance with the approach advocated by the ANC Guidelines [1] and BS 4142 [7]. As an A-weighted parameter does not constrain individual octave band noise levels, its weakness is that an intrusive tonal noise source could still comply with A-weighted noise limit. A penalty such as this will, in most cases, encourage good design practice (i.e. specification of non-tonal/impulsive installations). In situations where the risk of tonal/impulsive noise emission is unavoidable, then the installation is designed to the reduced noise limits.

Measurement period: These instructions are in accordance with the ANC Guidelines [1] and our own experience of fair measurement practice to adequately represent noise sources.

Frequency range: We recommend stipulating a minimum frequency range to avoid disputes, as a narrower frequency range could be shown (misleadingly) to comply with the A-weighted noise limit. However, it should be noted that designing to a wider frequency range (i.e. including 31.5 Hz and 8 kHz) is not realistic due to the lack of reliable source data and/or noise transmission prediction techniques at these frequencies. There are possible measurement reproducibility problems due to instrumentation tolerances at these frequencies which could lead to compliance disputes i.e. a different sound level meter on a different day could give a different A-weighted result for the same noise source. If such a dispute arose, the measured octave band levels from 63 Hz to 4 kHz could be extracted to calculate the A-weighted level.

In order to progress further, there are a number of issues which SBSA will need to consider when deciding what standards to adopt.

1	Should the above criteria apply to all dwellings, or differentiate between new-build, conversions or extensions with different sets of criteria?

It is recognised that services noise control may be more difficult for conversions and particularly for a conversion to multiple dwellings, where there is more likelihood that ducts and pipework will need to pass through a neighbouring dwelling in the same development. However, we believe that the same standard is still achievable through competent design. Where constructions are unknown, deterministic sound tests and/or boroscope investigations could be carried out.

Where noise control measures could compromise an historic building (e.g. de-mounting ceiling plasterwork to box-out ducts and/or pipework) then a similar approach to that of sound insulation between dwelling conversions could be employed. The SBSA Technical Handbooks include a Guide for Practitioners 6: Conversion of Traditional Buildings. Chapter 6 in Part 1: Principles and Practice [16] recognises that the sound insulation performance standards may not be practical in the case of some historic buildings undergoing a material change of use:

> *"6.2.1 [..] Each building is unique, which with its particular design and construction challenges the designer to arrive at solutions that provide the optimum sound insulation whilst preserving historic fabric."*

Services noise arising from a new extension could be slightly more challenging than a new-build dwelling, as it may be in closer proximity to neighbouring dwellings. However, we believe that the same standard is still achievable through competent design.

2	Should the criteria be expanded to apply to the 'origin' dwelling? i.e. inside the same dwelling which the installation is serving (other than installations serving multiple dwellings which is already included in the proposed criteria).

We expect that this inclusion would put a greater burden on the services design, primarily because the noise source will often be inside the receiver room and/or much closer to other receiver rooms than it would be to a neighbouring dwelling. It would also rely more heavily on accurate noise data from the equipment manufacturers, since equipment selection, installation and enclosure would be the only realistic design measures, rather than the sound insulation of separating constructions.

However, it could be argued that there is no reason why occupants of a new dwelling should not expect the same standard as their neighbours, particularly for essential services such as water pumps, heating, ventilation and drainage. However, any non-essential services which are under the control of that dwelling, such as air cooling in summer months, may not trigger the same degree of annoyance since the occupant can switch it off when necessary.

Nonetheless, we know from experience that occupants tend to be more tolerant of noise from their own services equipment, mainly because it is within their control and is usually a familiar/expected noise intrusion. Therefore, if SBSA wish to include this, it could be argued that relaxing the RMP suggested criteria by 10 dB would be pragmatic and reasonable to apply to the origin dwelling (i.e. subjectively twice as loud as the noise limit from a neighbouring dwelling). However, this may not be acceptable for continuous essential services such as ventilation, in which case we suggest that the noise from such services within the origin dwelling, should be limited to the RMP suggested criteria.

3	Should the criteria take account of rooms which could be interchangeable in use? i.e. services designed to meet a living room standard, may not be sufficient if that room is used as a bedroom instead.

It may appear that this is an issue primarily concerning flats and bungalows rather than 2-storey houses, since bedrooms will usually be the habitable rooms upstairs and living rooms will usually be the habitable rooms downstairs (however, this may not be the case throughout the lifetime of the house). We assume that the main room of a studio flat would always be designed to meet the bedroom standard.

As the RMP suggested criteria stands, the designer/developer could circumvent the design requirements, for example, by identifying the room next to the lift shaft as a living room. By doing so, the lift noise need not be designed to meet the stricter bedroom standard, even though this room may be more likely to be used as a bedroom if it is not the largest room in the dwelling.

The only robust way to avoid this eventuality, would be to remove the living room standard and apply the bedroom standard to all habitable noise-sensitive rooms (as is the case for most of the European Building Regs reviewed in Chapter 4). This would obviously put a greater burden on the design and may entail a less flexible room layout, i.e. living rooms could no longer be regarded as less noise-sensitive than bedrooms. However, a well thought-out room layout could still locate hallways/corridors and less-sensitive rooms such as kitchens and bathrooms adjacent to the building services noise sources.

A less onerous option might be to ensure that the designer/developer takes a realistic approach to the designation of living room and bedrooms. For example, a dwelling which is marketed as 2 bedrooms, should have at least 2 rooms that meet the bedroom standard. We recommend that this issue is opened up for wider consultation, to understand the full implications and practicalities. For example, we assume that it is not reasonable to legislate against the possibility of a 2-bed flat, used as 3 bedrooms (for example where a large kitchen could double as the living room).

4 Should the criteria be expanded to include conservatories and/or private exterior areas such as balconies and roof terraces?

These areas are increasingly regarded as ‘outdoor living rooms’ with the expectation that they can be used at anytime free of noise nuisance. However, it needs to be recognised that this decision would add a further burden on the services design, since the naturally occurring noise attenuation between dwellings would be less. Also, in some cases, the external visual impact of the acoustic control measures may be unreasonable. For example heating or ventilation exhausts are more likely to require an acoustically attenuating cowel or hood which are generally more bulky than a standard cowel or simple flue or louvre.

If the criteria included private outdoor areas, it would be less appropriate to use a single absolute noise limit. For example, new housing developments can be approved in areas where transportation noise impact is as much as 71 dB L_{Aeq} (i.e. upper limit of PAN56 NEC ‘C’) during the day. In which case, an outdoor noise limit of 50 to 55 dB L_{Aeq} (BS 8233) would be unnecessarily low. Conversely, an outdoor noise limit of 50 to 55 dB L_{Aeq} could be too high in very low level ambient noise areas (≤ 35 dB L_{Aeq}). To minimise the risk of over or under-design, the services noise limit could be based on the background noise level (taken from a dedicated noise measurement, the planning application noise survey or perhaps publicly available noise mapping output). However, this would add a further burden on the information needed to do the design, since the rest of the criteria could be limited to ‘desktop’ prediction (other than perhaps, building conversions).

5 Should the noise character penalty also apply to a noise source which is purely intermittent?

The noise nuisance from intermittent sources such as lifts is a major concern (a significant number of other building services could also be described as intermittent, such as combi-boilers and water pumps). In terms of the WHO guidance, 45 dB L_{Amax} represents the onset of potential sleep disturbance, therefore, in our opinion, this is a strict enough noise limit, such that the majority of people would not complain, regardless of whether it is a constant or intermittent noise source. The noise source may still be audible and noticeable by virtue of its intermittency but as discussed at the inception meeting, the expectation here is not to achieve inaudibility.

It is important to ensure that the start and stop noise characteristics of an intermittent noise source such as lift noise are not ignored, as this is often what attracts attention. During compliance testing, the measurement must include the entire lift operation cycle from the doors opening and lift moving to the lift stopping and the doors opening then closing. By ensuring that the criteria stipulates that the measurement is no longer than the lift cycle, then we are avoiding the possibility of the L_{Aeq} noise level being ‘artificially’ lowered by a period of no lift noise. If it is agreed that an intermittent noise character penalty is not required, then the criteria notes should state this explicitly, otherwise this could lead to uncertainty and/or dispute between designer and building control.

6 Should the criteria include low frequency noise restrictions?

We are aware that it is possible to be disturbed by a low frequency noise, without exceeding the A-weighted noise limits (since the A-weightings at low frequencies attenuate noise far more than at higher frequencies).

However, there are far fewer instances of problems attributable to domestic services, compared to industry or domestic appliances such as refrigerators and washing machines, which are outwith the scope of this report. From a survey [17] of 210 UK local authorities and 453 low frequency noise complaints (from 1987 to 1989) the % of complaints from identified sources in descending order were as follows: factories, music, traffic/vehicles, commercial premises, foundries, electrical installations, quarries/blasting, construction sites, mining, combustion, railways, aircraft, oil and gas rigs and other sources. The study deduced that there may be 12% of low frequency noise complaints for which a positive identification of the source of the noise could not be made.

To help local authorities deal with complaints about low frequency noise there is a growing body of DEFRA-funded research work, which includes a proposal for an assessment procedure and criteria for Environmental Health Officers to follow when investigating a low frequency noise complaint [18]. It involves comparing measured L_{eq} third-octave band data against third-octave band threshold levels between 10 Hz and 160 Hz, above which is an indication of a source of low frequency noise that could cause disturbance. If the noise occurs only during the day then a 5 dB relaxation may be applied to all third octave band threshold levels. If the noise is steady then a 5 dB relaxation may be applied to all third octave band threshold levels. The character of the sound is also important and an audio recording is recommended to playback and assess at an amplified level.

With regards to domestic building services, electrical installations such as transformers, generally exhibit low frequency content around 100 Hz. The aforementioned DEFRA threshold levels around this frequency region correspond to NR15. We would suggest that SBSA consider expanding the noise criteria to include an extra requirement for major electrical installations, such as transformers, so that this noise source does not exceed NR15 between 31.5 Hz and 125 Hz during the night-time, but relaxed to NR20 if the noise is steady and/or operates only during the daytime. Alternatively, to avoid reference to NR, octave band limits of 66, 47 and 35 dB L_{Aeq} at 31.5, 63 and 125 Hz respectively could be set for the night-time, with +5 dB relaxation if the noise is steady and/or operates only during the daytime.

7 Should there also be an L_{AFmax} noise limit for the living room?

We do not consider that brief peaks are as important to control in the living room. However, this is something that SBSA could consider to further reduce the risk of noise nuisance. If so, we would not suggest a noise limit any lower than 55 dB L_{AFmax} for living rooms.

Commissioning measurements

We recommend that building services noise for new dwellings is subject to pre-completion measurements. Otherwise, building services design may not receive any greater attention with regards to noise control than it does now. We recommend that the criteria is accompanied by a noise measurement method for checking compliance, otherwise this is open to interpretation and consequently different results depending on the measurement method.

The noise measurement method need not be complicated and could be carried out by a competent person with a handheld sound level meter (Class 1 or 2 as defined in BS EN 61672-1:2003). There would be no need to carry out any sound insulation testing or room reverberance measurements in order to check services noise levels. Pre-completion testing would normally occur in an unfurnished room prior to occupation, which would mean that building services noise levels would be slightly higher than in a furnished room. If a measured noise level was a marginal failure, then it would be acceptable to standardise the noise level to a reference reverberation time of 0.5 seconds (as described in §3.4 of BS EN ISO 140-4:1998 [19]) in order to demonstrate compliance (which would require a room reverberance measurement or calculations based on the room volume and surface finishes).

The ANC Guidelines [1] are a useful reference with regards to prescribing a compliance test method. These guidelines were developed by an ANC working group for use in the following circumstances:

- where there is a dispute between parties as to whether a completed installation complies with a noise requirement, and

- where the project specification makes no provision for one or more of the procedures in these guidelines.

On an occasion, it may be difficult to measure building services noise, free of significant extraneous noise, particularly when checking for noise as low as 30 dB L_{Aeq}. However, in such circumstances, the actual building services noise can be 'extracted' from the total noise. The aforementioned ANC Guidelines describe this exercise as follows:

> *"Specific noise:* *The noise caused by the plant or equipment under investigation.*
>
> *Residual noise:* *The noise caused by prevailing sources, in the absence of the noise of the plant or equipment under investigation.*
>
> *Total noise:* *The noise caused by a combination of prevailing sources and the plant or equipment under investigation.*
>
> *The specific noise level is obtained by logarithmically subtracting the residual noise level from the total noise level. If the residual noise level is less than 10 dB below the specific noise level, then measurements should be made at a time when the residual noise level is at a reasonable minimum. If the residual noise level is within 3 dB of the total noise level the calculated specific noise level is subject to considerable uncertainty."*

With regards to the measurement position within the room, the ANC Guidelines state that it may be necessary to measure at a number of positions to locate the noisiest normally-occupied position in the room. They define 'normally-occupied positions' as follows:

> *"a) The height of the measuring microphone should be between 1.2 and 1.5 m from the floor.**
>
> *b) Measurements should not be taken with the microphone less than 1.5 m from any relevant noise source, such as a grille, diffuser, open window or item of plant except where room dimensions and a) above make this impossible, in which case, the maximum practicable distance should be adopted.*
>
> *c) Measurements should not be taken with the microphone less than 1 m from any sound-reflecting surface except where room dimensions and/or a) and b) above make this impossible, in which case, the maximum practicable distance should be adopted."*

*However, it could be argued that this should be ~ 0.7 m above floor level for bedrooms in order to represent bed height.

We recommend that the noise measurements are carried out with the plant operating at its normal/typical duty and the room in its worst affected condition; for example in a naturally ventilated space, this might be with the window open, if the neighbouring dwelling has a noisy boiler flue (if necessary, this noise level would be extracted as described previously, if there are extraneous sources such as road traffic). If the window did not influence building services noise ingress, then the measurements would be undertaken with windows closed to avoid masking from external sources.

<u>Commissioning cost</u>

It is estimated that the cost of carrying out commission testing could be in the order of £250-£500 depending on the number of rooms required to be assessed. If Building Control requires sound insulation testing and the background noise level is low enough, then services noise commissioning could be carried out at the same time, in which case the cost for the services noise check may be less than £250.

7 Design guides

Annex B contains a sample of design guides that we have devised for lifts, refuse chutes and pumps. Each guide gives construction and installation advice to minimise the risk of noise nuisance complaints.

Originally it was envisaged that this report would include case studies or design guides for different building types. However, from our experience of previous noise complaints, it was agreed that this approach would not be the most worthwhile, since the building type does not have a significant influence over the risk of noise complaints from building services. The separating constructions are important, but it is much more important to 'tackle the problem at source' rather than rely on sound insulation of the building construction.

We have offered design guides rather than case studies, because we believe that one case study will not reveal all the possible problems of a building services noise source.

Prediction analysis techniques

The subject of prediction analysis techniques is outwith the original scope of this contract. Ultimately it is for the acoustics consultant or designer to use their preferred method of noise prediction and noise control design.

The SBSA guidance should encourage the designer to make the best-practice design decisions and make them aware of occasions when they should seek the specialist services of a competent acoustician.

In carrying out the prediction analysis, an acoustician may use one of the parts from the BS EN 12354 series of standards [20]. However, prEN 12354-5: 2007 which is planned to deal with building services equipment has not yet been published.

8 Equipment testing & measurement standards

There are British and European standards available which standardise the method for noise testing specific items of building services equipment. From a search of BSI online, these standards are listed at Annex D.

Reliable and comprehensive noise data, ideally in accordance with the relevant standard is important to designers and acousticians to enable them to design the installation and separating constructions to meet the insitu noise limits. These test standards also ensure uniformity of data which aid in ranking and selection of quiet equipment.

In our experience, not all domestic building services manufacturers/suppliers are providing noise data to a useful standard.

9 Micro wind turbine noise

A new type of building services noise source is the micro wind turbine which can potentially be installed on the roof or façade of houses or flats, to provide a renewable energy source to one or more dwellings.

The main suppliers in Scotland do not appear to have published detailed noise and vibration information regarding their equipment.

We are aware that the Scottish Executive has recently published a report reviewing the General Permitted Development Order and making recommendations for changes to its form and content [21]. Within this report are recommended internal noise limits due to micro wind turbines:

> *"[..] a Permitted Development (PD) noise constraint should be imposed on all installations. We propose that this be expressed as a condition, requiring that noise emitted by the installation should not be received at a level exceeding 45dB(A) absolute inside a room of any neighbouring property; and 35dB(A) inside a room in which persons might reasonably be expected to sleep, and in which windows are open to allow reasonable ventilation."*

It is likely that these noise limits are based on the PAN56 [6] internal noise criteria for transportation noise. They do not include any protection against possible tonal noise and they are 5-10 dB less stringent than the RMP recommended services noise criteria.

In the absence of detailed information or previous experience with micro-wind turbine installations, we have been asked to make a preliminary field investigation in order to provide an indication of the noise emission and vibration input to a building due to a micro wind turbine. To this end, noise emission and vibration measurements of a micro wind turbine installation have been conducted by RMP Acoustics. The full survey details and detailed results are presented in Annex C. There were four wind turbines mounted on each corner at the top of a lift shaft, however, not all of them appeared to be functioning properly, so the measurements were influenced by just one of them.

We are well aware of the limitations of a 'one-off' assessment such as this. A full detailed investigation would require long-term noise monitoring i.e. to capture all possible wind characteristics and/or ideally a laboratory controlled environment such as a wind tunnel. This 'one off' assessment does not provide a robust understanding of the maximum possible airborne noise emission for different types of micro wind turbines or structure-borne noise issues for micro wind turbines mounted in different ways, on different parts of a building, for different building types.

The wind turbine that we measured exhibited significant high frequency energy content, centred around 2 kHz, but without a marked tonal component. Subjectively, this correlated to a “swish” noise from the wind turbine blades, which became apparent above a certain blade rotation speed. Due to the high frequency content the noise was directional, in that it was less audible when the wind turbine faced away from the listener and also less audible directly below the wind turbine.

This high frequency content pushed the ambient noise level up from 53 to 63 dB L_{Aeq} at 2 m away from the hub. Whilst this result cannot necessarily be used universally for all wind turbines, it indicates that for this particular turbine, the recommended bedroom services noise limit of 30 dB L_{Aeq} would be achieved inside a room with an open window, as long as the wind turbine is at least 20 m away. This distance would be reduced if there was any intervening building structure or other acoustic screening to attenuate the noise propagation.

The measured vibration levels did not exceed the BS 6472 base curve for r.m.s. acceleration in the horizontal plane [22] which means that perceptible vibration is unlikely to be an issue.

From the vibration graph in Annex C it is clear that there is high frequency vibration input whenever the turbine blades rotate above a certain speed, so this energy could be transmitted as structure-borne noise. This particular wind turbine had 10 mm thick resilient material inserted between the turbine pole and most of the wall mountings, although the bottom mounting where our accelerometer was positioned, did not appear to have this. We understand that a top floor resident had complained about noise which prompted the supplier to insert this resilient material. However, at the time of our measurements there were no longer any top floor residents so we were not able to confirm the nature of the noise nuisance or check whether this remedial action had solved their noise problem.

Further research is required in order to provide full guidance on the control of noise and vibration from micro wind turbines.

10 References

[1] Association of Noise Consultants ANC-9701 *ANC Guidelines - Noise Measurement in Buildings. Part 1: Noise from Building Services* (August 1997).

[2] BS 8233: 1999 *Sound insulation and noise reduction for buildings. Code of practice.*

[3] World Health Organization (WHO) *Guidelines for community noise* (1999).

[4] Building Research Establishment (BRE) & Construction Industry Research and Information Association (CIRIA) *Sound control for homes* (1993).

[5] Chartered Institution of Building Services Engineers *CIBSE Guide A - Environmental Design* (January 2007).

[6] Planning Advice Note 56 ‘Planning and Noise’ PAN56 (1999).

[7] BS 4142: 1997 *Method for rating industrial noise affecting mixed residential and industrial areas*.

[8] Section 5: Noise of the Technical Handbooks for the Building (Scotland) Regulations 2004.

[9] Building Regulations 2000 (England and Wales) Approved Document E *Resistance to the passage of sound* (2003 edition, as amended 2004).

[10] Building Regulations 2000 (England and Wales) Approved Document F *Means of ventilation* (2006 edition).

[11] Building Regulations 2000 (England and Wales) Approved Document J *Combustion appliances and fuel storage systems* (2002 edition).

[12] Department for Communities and Local Government *Code for Sustainable Homes Technical Guide* (March 2007).

[13] The Noise Insulation Regulations 1975 Statutory Instrument No. 1763.

[14] The Noise Insulation (Scotland) Regulations 1975 Statutory Instrument No. 460.

[15] Sheridan, L.; Visscher, H.J. & Meijer, F.M. (2003) *Housing and Urban Policy Studies 24 Building regulations in Europe Part II A comparison of technical requirements in eight European countries*. DUP Science, Delft University Press.

[16] Guide for Practitioners 6: *Conversion of traditional buildings, Application of the Scottish Building Standards, Part 1 Principles and Practice*. Historic Scotland (2007).

[17] Tempest, W. (1989) *A survey of low frequency noise complaints received by local authorities in the United Kingdom*. Journal of Low Frequency Noise, Vibration and Active Control **8**, pp45-49.

[18] Department for Environment Food and Rural Affairs DEFRA Contract NANR45 *Proposed criteria for the assessment of low frequency noise disturbance* (February 2005).

[19] BS EN ISO 140-4: 1998 *Acoustics. Measurement of sound insulation in buildings and of building elements Part 4: Field measurements of airborne sound insulation between rooms*.

[20] BS EN 12354 *Building Acoustics - Estimation of acoustic performance of buildings from the performance of elements*

[21] Scottish Executive Development Department *Review of the General Permitted Development Order 1992: Final Report* (March 2007)

[22] BS 6472: 1992 *Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)*.

Annex A Glossary of acoustical terminology

Airborne sound

Sound propagating through air as a medium rather than through solids or the structure of a building.

Airborne sound insulation

Sound insulation that reduces the transmission of airborne sound between rooms.

Structure-borne sound

Structure-borne sound applies to processes by which vibrational disturbances of the build structure in the audio-frequency range transmit energy to other parts of the building and is radiated as airborne sound.

Flanking element

Any building element that contributes to the airborne sound or impact transmission between rooms in a building which is not the direct separating element (i.e. not the separating wall or separating floor).

Flanking sound transmission

Airborne or impact sound transmitted between rooms via flanking elements instead of directly through separating elements or along any path other than the direct path.

Sound pressure level and decibel (dB)

The range of audible sound pressures is approximately 0.00002 to 200 Pascals. The sound pressure level is 10 times the common logarithm of the ratio of the square of sound pressure under consideration to the square of the standard reference pressure of 0.00002 Pascals. This quantity uses decibel notation and presents this range in a more manageable form, 0 dB to 140 dB.

Frequency (Hz)

The number of pressure variations per second. This is subjectively perceived as pitch.

Frequency spectrum

Analysis of the relative contributions of different frequencies that make up a noise.

Octave bandwidth

A range of frequencies defined by an upper limit which is twice the lower limit. Octave bandwidths are identified by their centre frequency.

Noise Unwanted sound.

Ambient noise Totally encompassing sound in a given situation at a given time usually composed of sound from many sources near and far.

Tonal noise Having a discrete, or isolated frequency component.

Broadband noise Having approximately equal contributions from all frequencies.

A-weighted sound levels

These are sound pressure levels which have been adjusted to take account of the fact that the human ear is not equally sensitive to all frequencies. Sound level meters have an electrical "A" weighting circuit to simulate the frequency response of the ear. Its units are expressed as dB(A).

Equivalent Continuous Sound Level $L_{Aeq,T}$

This is the steady sound level which would produce the same A-weighted acoustic energy over a given time period T, as the actual time varying sound.

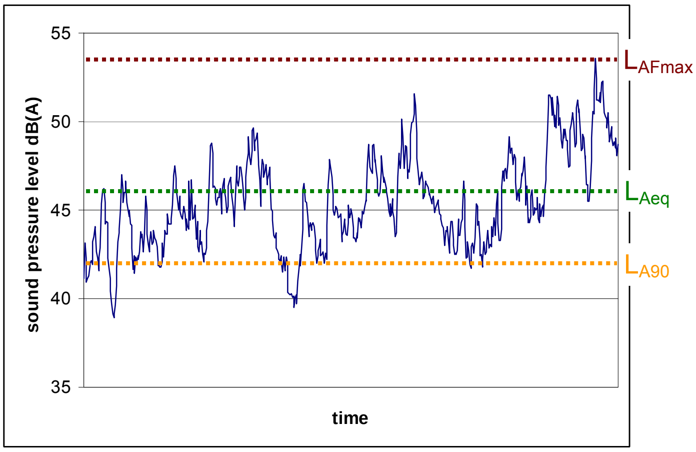
Maximum Sound Level L_{AFmax}

This is the maximum A-weighted sound level measured during the measurement period. "F" denotes that the sound level meter was set to a fast time constant (averaging over 125 ms).

Background Noise Level $L_{A90,T}$

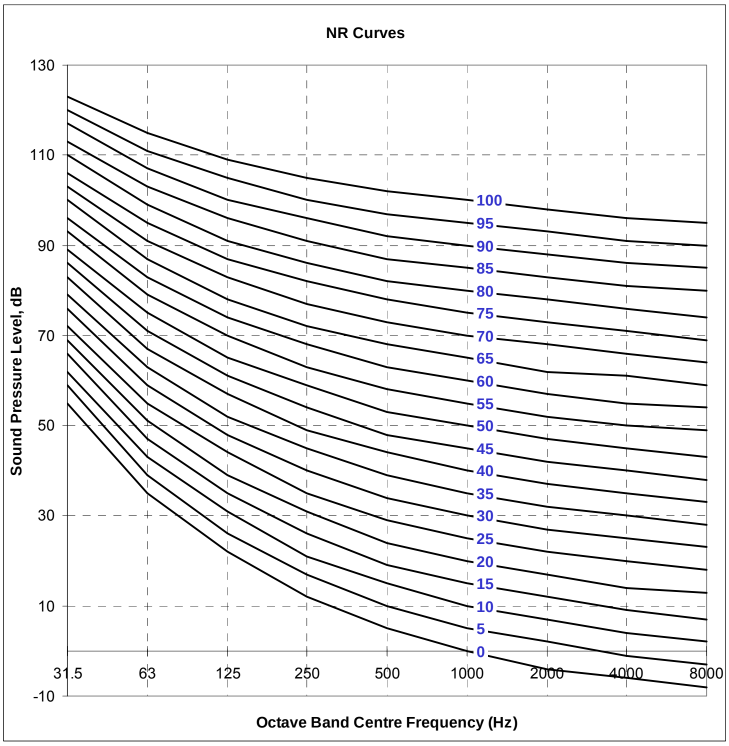
The L_{A90} is the A-weighted sound level exceeded for 90% of the time period, T and has been adopted as a good indicator of the 'background' noise level.

Example of time-varying sound level, indicating L_{AFmax} L_{Aeq} and L_{A90} parameters:



Noise Rating (NR)

Noise rating (NR) is a method for assigning a single number rating to a noise spectrum. It can be used to specify the maximum acceptable level in each octave band of a frequency spectrum, or to assess the acceptability of a noise spectrum for a particular application. The NR curves are defined in BS 8233: 1999.



$L_{I;A}$ used in The Netherlands

Averaged A-weighted standardised sound pressure level over 5 octave bands 125, 250, 500, 1000 and 2000 Hz.

L_{nAT} used in France

A-weighted sound pressure level averaged over a period of time T, standardised to a reference reverberation time of 0.5 seconds for dwellings.

L_{In} used in Germany

Linear sound pressure level (no weighting).

L_r used in Germany

A-weighted sound pressure level averaged over the duration of noise exposure.

L_{pA} used in Sweden

A-weighted sound pressure level.

L_{pAFmax} used in Sweden

Maximum A-weighted sound pressure level with fast time weighting (i.e. the same as L_{AFmax}).

$L_{Aeq\ adj}$ used in Australia

A-weighted equivalent continuous sound pressure level, adjusted for noise character (tonality and impulsiveness).

Annex B Design guides

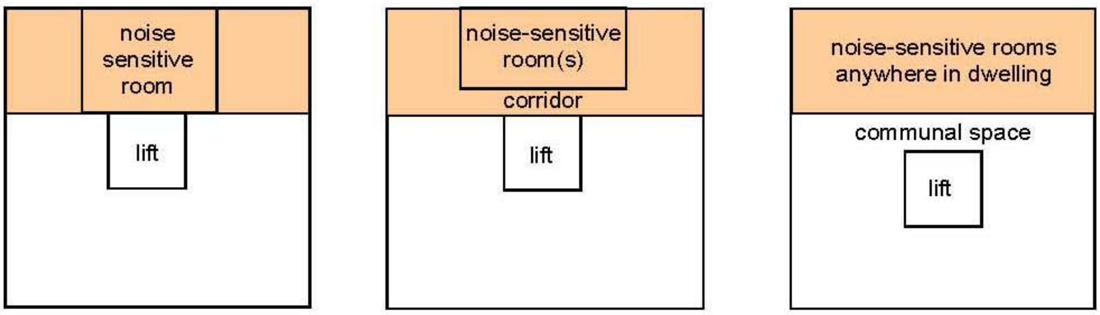
Design Guide

This design advice applies to the traditional lift mechanism of an electric traction engine pulling on wire ropes attached to the top of the lift car. Hydraulic lifts, high-speed lifts and machine room-less (MRL) lifts have additional/different noise considerations so specialist advice is recommended.

Lift noise in dwellings

Where a lift is required within a residential development, it is important not only for the building services engineer to consider noise & vibration emission in their specification and selection of the lift system, but also for the architect to consider the acoustic design of the building at an early stage. Lift noise is transmitted as airborne and structure-borne noise but the most common cause of lift noise complaints or design failure is due to structure-borne noise transmission via the building.

The most effective approach to control lift noise is to avoid locating the lift shaft directly adjacent to dwellings. If this is impractical, then avoid locating noise-sensitive rooms, such as a bedroom or living room directly adjacent to the lift shaft or lift motor room. If this is not possible, then avoid locating a noise-sensitive room directly adjacent to a lift shaft wall which has the guide rail(s).



Poor **Better** **Best**

Ideally, the lift shaft should be structurally de-coupled from the surrounding structure as far as possible.

It is required that the lift shaft wall achieves a level of airborne sound insulation in line with Section 5 of the Building (Scotland) Regulations 2004. Where it is not possible to avoid locating a habitable room next to a lift shaft, to reduce structure-borne noise transmission it is recommended that in addition to the lift shaftwall, an independent wall lining is constructed on the dwelling side of the common wall.

It should not be necessary to locate a lift shaft against an external wall. However, if this is unavoidable, then the lift shaft should have a separate inner core, structurally de-coupled from the external wall.

Independent wall lining:
A metal or timber frame offset from the lift shaft wall by a minimum of 30 mm, with no direct contact and connected only to the floor and ceiling. An absorption layer of 50 mm mineral wool (~ 15 kg/m³) or equivalent, suspended between the frame and finished with two layers of dense gypsum-based board (≥ 13 kg/m²). Where service zones or sockets are required it is recommended that a sacrificial service zone is formed using a timber or metal strap and lined with gypsum-based board.

Where a lift shaft adjoins a less noise-sensitive room, such as a bathroom or kitchen then the independent wall lining could be reduced to one layer of standard weight gypsum-based board (≥ 10 kg/m²).

	Lift equipment
Vibration isolation	Generally, better vibration isolation can be achieved if the lift motor/plant room is located within the basement, instead of the top/roof of the building. The lift plant should be located on a large inertia block supported on resilient mounts with a static deflection appropriate to the mass and forcing frequency of vibration for the overall assembly. There should be no rigid connection between the lift plant and the building structure, or the lift guide system. The lift car guide shoes and/or the lift shaft guide rails should be resiliently mounted. The lift design should reduce the possibility of flat spots developing on the guide shoes, which cause noise. It is recommended that the lift switchgear cabinet is resiliently mounted to the building structure and seals fitted to the cabinet door(s). Alternatively, electronic switching would avoid 'moving parts' clicking noise.
Airborne noise control	The lift motor/plant room separating constructions should comply with Section 5 of the Building (Scotland) Regulations 2004. Where it is not possible to avoid locating a habitable room next to the lift plant room, to reduce structure-borne noise transmission it is recommended that in addition to the Section 5 compliant construction, an independent wall lining is constructed on the dwelling side of the common wall. It should not be necessary to locate lift plant in an attic or roof void common to the top floor dwellings, otherwise seek specialist advice to achieve the necessary sound insulation between lift plant and dwellings. Ventilation routes for lift motor rooms should terminate as far as possible from a dwelling window; even so, they may require to be acoustically attenuated.

Other lift noise:
Lift announcements, chiming or other aural indicators should be set to an appropriate level to avoid disturbance. Lift doors with a slow operation speed and nylon runners minimise noise.

References CIBSE Guide D: *Transportation systems in buildings*, 2005.
Sound control for homes, BRE/CIRIA, 1993.
Noise control in building services, SRL Ltd, Pergamon Press, 1988.

Design Guide

This design advice refers to all pumps, including water supply, waste disposal, gas supply and low and zero carbon technologies such as ground and heat source pumps. The advice applies to both pumps within dwellings and those in communal space serving multiple dwellings.

Pump noise in dwellings

Where a pump is required it is important not only for the building services engineer to consider noise & vibration emission in their specification and selection of the pump, but also for the architect to consider the pump location and acoustic design of the separating building elements.

Pump noise can be a problem in terms of both airborne and structure-borne noise. However, noise complaints or design failure are often due to pump vibration causing structure-borne noise transmission.

The most effective approach in controlling pump noise is to avoid locating a pump directly above, below or adjacent to a noise-sensitive room in a neighbouring dwelling.

	Pump installation
Vibration isolation	Avoid locating the pump on a lightweight wall or shelf. The pump assembly should be mounted on vibration isolators or resilient mat selected on the basis of the mass and the rotational frequency of the pump. For large pumps, the assembly should be mounted on a concrete inertia block supported by anti-vibration mounts selected on the basis of the pump and inertia block mass and the rotational frequency of the pump. All pipework from the pump should be fitted with a flexible connector to reduce the risk of vibration being transmitted along the pipes. Avoid fixing the pipework to lightweight building elements or on a wall or soffit adjoining a neighbouring dwelling. The first resilient pipework support should be mounted/hung immediately after the flexible connector. Avoid any rigid electrical conduits connected to the pump.

	Pump installation
Airborne noise control	Reliable noise data for the pump should be obtained at the design stage in order to select a suitable acoustic enclosure and/or design separating floor, wall and door constructions with sufficient sound insulation. At minimum, the constructions separating a dwelling from a shared pump room or a pump in a neighbouring dwelling should comply with Section 5 of the Building (Scotland) Regulations 2004 (under review). The door to a pump room should have good perimeter sealing (including the threshold where practical) and a minimum mass per unit area of 25 kg/m² or a minimum weighted sound reduction index of 29 dB R_w. All services penetrations through the acoustic enclosure or sound-insulation critical floor or wall constructions should be well sealed with non-hardening sealant.

References *Sound control for homes*, BRE/CIRIA, 1993.

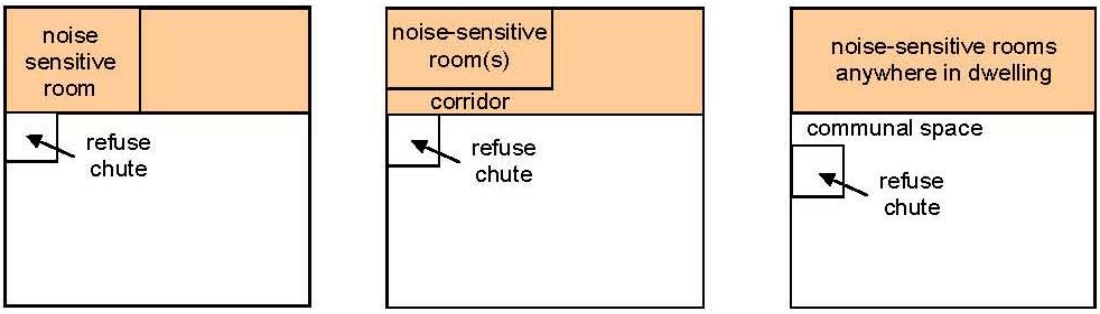
Design Guide

This design advice applies to lightweight refuse chutes such as aluminium, steel or plastic. Concrete chutes may be less problematic.

Refuse chute noise in dwellings

Where a refuse chute is required within a residential development, the architect should consider the acoustic design of the building at an early stage. Refuse chute noise is transmitted primarily as structure-borne noise from the impact of refuse against the chute walls and landing in the bin (at the end of the chute).

The most effective noise control is to avoid locating the refuse chute or bin storage room directly adjacent to dwellings. If this is impractical, then avoid locating noise-sensitive rooms, such as a bedroom or living room, directly adjacent to the refuse chute or bin storage room.



Poor **Better** **Best**

It is required that the refuse chute wall achieves a level of airborne sound insulation in line with Section 5 of the Building (Scotland) Regulations 2004. Where it is not possible to avoid locating a habitable room next to a refuse chute, to reduce structure-borne noise transmission it is recommended that in addition to the refuse chute wall, an independent wall lining is constructed on the dwelling side of the common wall.

Independent wall lining:
A metal or timber frame offset from the refuse chute wall by a minimum of 30 mm, with no direct contact and connected only to the floor and ceiling. An absorption layer of 50 mm mineral wool (~ 15 kg/m^3) or equivalent, suspended between the frame and finished with two layers of dense gypsum-based board (≥ 13 kg/m^2). Where service zones or sockets are required it is recommended that a sacrificial service zone is formed using a timber or metal strap and lined with gypsum-based board.

Where a refuse chute adjoins a less noise-sensitive room, such as a bathroom or kitchen then the independent wall lining could be reduced to one layer of standard weight gypsum-based board (≥ 10 kg/m^2).

Refuse chute internal lining:
Where there is a bend in the refuse chute, the inside should be lined with a minimum of 10 mm abrasion-resistant rubber. Depending on the height and dimensions of the refuse chute it may be advisable to line the entire chute.

Refuse chute mountings:
The refuse chute should be resiliently mounted to the shaftwall and ideally not on the side adjoining a dwelling.

Refuse chute doors:
The openings to the refuse chute at each floor should be such that the doors do not impart excessive vibrational energy into the lightweight chute when closed.

Bin storage room:
Ideally, the floor of the bin storage room should be structurally de-coupled from the rest of the floor construction, typically using a floating floor screed. The bin positioned at the refuse chute termination should not be in contact with any wall adjoining a dwelling. Also, it would be good practice to fix resiliently mounted skirting rail around the room perimeter so that the bin cannot hit a wall when it is moved outside for collection.

Annex C Wind turbine noise & vibration measurements

Noise source: Windsave WS1000 wind turbine (1 kW rated power).

Location: Rooftop of a nursing home in Glasgow.

Access granted by: Glasgow City Council.

RMP personnel: Rebecca Hutt BEng MIOA and Dr Elena Prokofieva BSc MSc PhD.

Date: Thursday 26th July 2007.

Measurement instrumentation:

Noise: B&K Modular Precision Sound Analyser Type 2260 (S/N 2399619)
B&K Prepolarised Condenser Microphone Type 4189 (S/N 2386220)
B&K Sound Level Calibrator Type 4231 (S/N 2393980)

Vibration: B&K Modular Precision Sound Analyser Type 2260 (S/N 2120171)
B&K Accelerometer Type 4384 (S/N 1208521)
B&K Calibration Exciter Type 4294 (S/N 2532254)

Microphone position: At the same height as the wind turbine hub, approximately 5.2 m above the main roof area and approximately 2 m from the wind turbine hub, as shown in the photo overleaf.

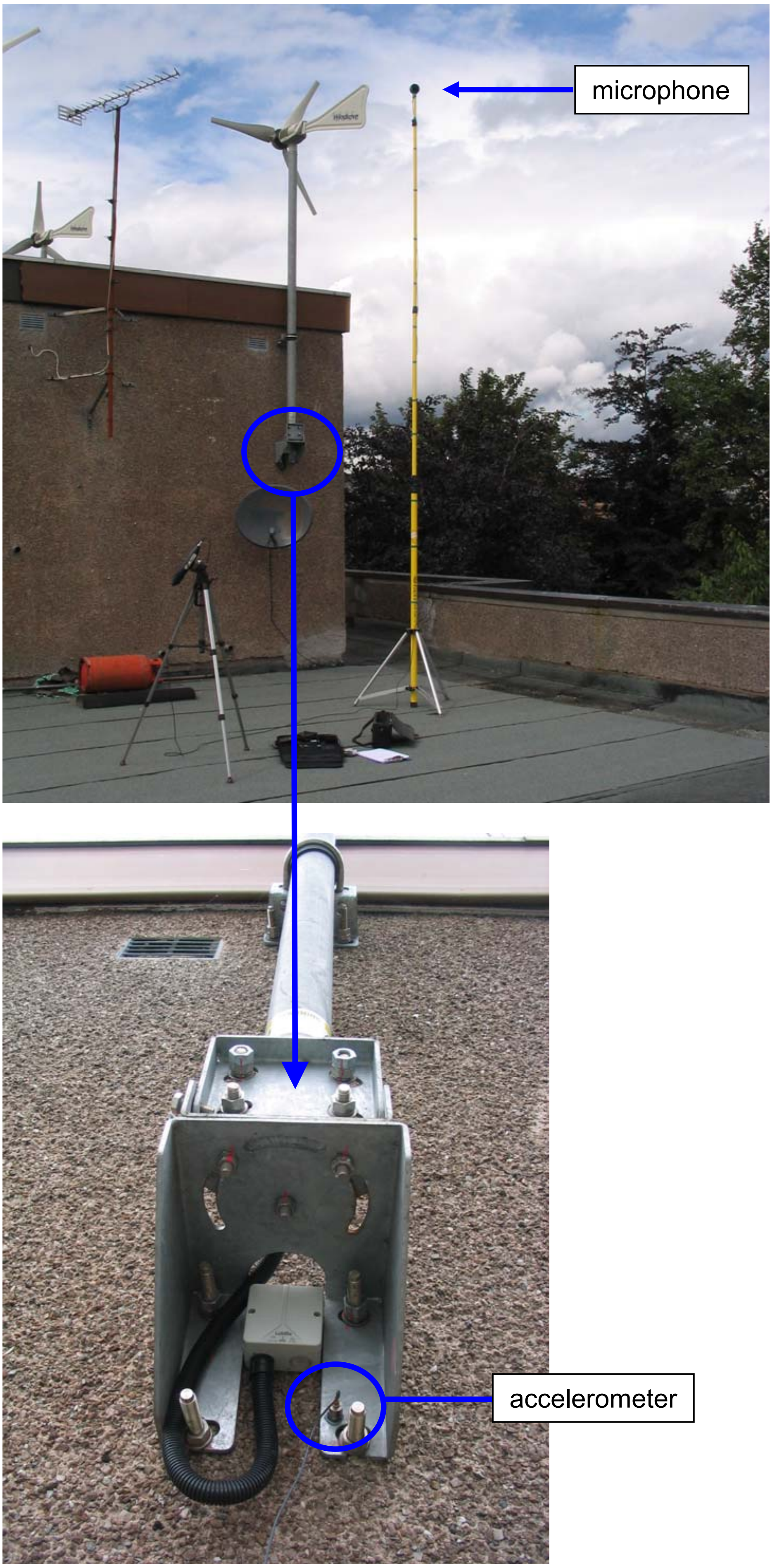
Accelerometer position: In the horizontal plane, on the lowest wall mounted bracket (rather than the pole itself) as shown in the photo overleaf.

Wind speed/power output: Unknown at the height of the wind turbine, however the wind speed at 1.5 m above roof level varied around 4 m/s. From the control panel, it was noted that the cumulative total before and after the survey remained the same at 15.8 kWh.

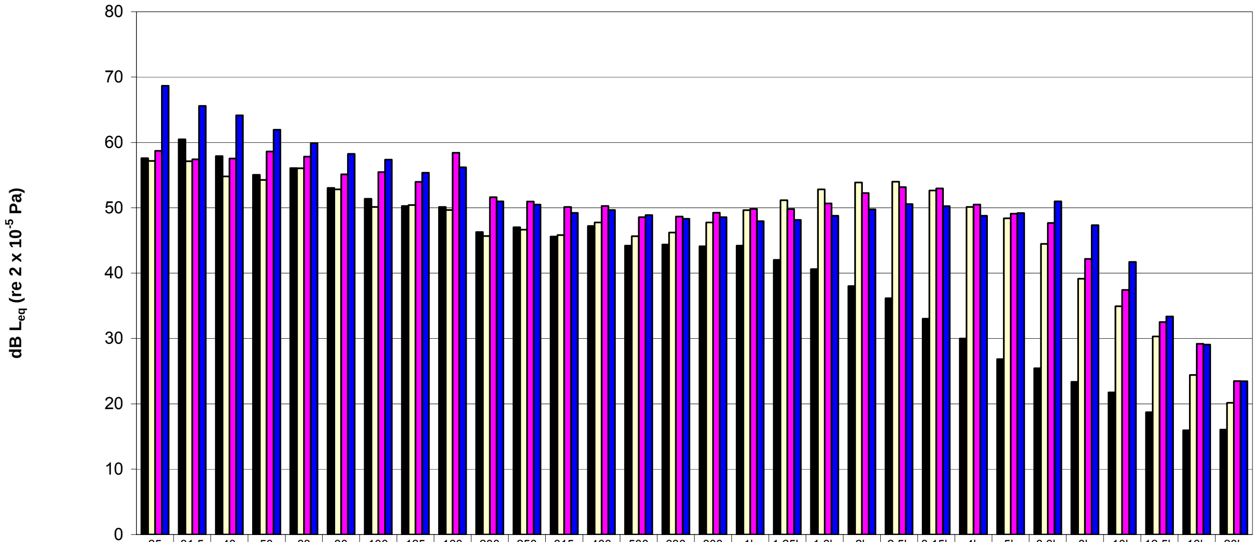
Method: The noise & vibration measurements were started as soon as the wind turbine noise was clearly audible and stopped before the wind turbine became inaudible above the background noise level. The audible noise was a "swish" from the wind turbine blades, which became apparent above a certain blade rotation speed. This "swish" noise was directional, in that it was less audible when the wind turbine faced away from the listener and also less audible directly below the wind turbine. The noise measurements were significantly influenced by air conditioning plant at the other end of the roof. Therefore, background measurements were made (i.e. when the wind turbine blades were static) in order to show the wind turbine noise contribution.

Noise data: From a selection of 12 measurements (duration ≥ 10 seconds), the 3 highest results are presented here in terms of A-weighted and third-octave band L_{eq} and L_{Fmax} (additional parameters are also available).

Vibration data: From a selection of 8 measurements (duration ≥ 10 seconds), the 4 highest results are presented here in terms of third-octave band r.m.s. acceleration.


microphone
accelerometer

L_{eq} measured noise
2 metres from Windsave Turbine
by RMP Acoustics on 26 July 2007

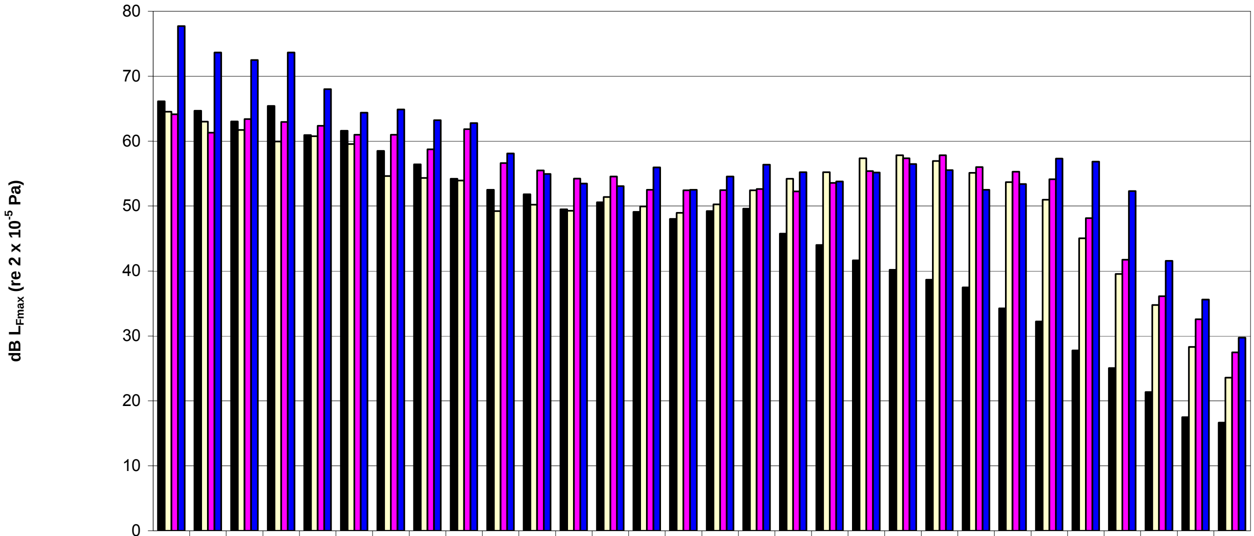


	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k	10k	12.5k	16k	20k
Static Turbine dB Leq	58	60	58	55	56	53	51	50	50	46	47	46	47	44	44	44	44	42	41	38	36	33	30	27	25	23	22	19	16	16
17 secs dB Leq	57	57	55	54	56	53	50	50	50	46	47	46	48	46	46	48	50	51	53	54	54	53	50	48	44	39	35	30	24	20
10 secs dB Leq	59	57	58	59	58	55	55	54	58	52	51	50	50	49	49	49	50	50	51	52	53	53	51	49	48	42	37	32	29	23
19 secs dB Leq	69	66	64	62	60	58	57	55	56	51	51	49	50	49	48	49	48	48	49	50	51	50	49	49	51	47	42	33	29	23

1/3 Octave Band Centre Frequency (Hz)

Static Turbine (background)	53 dB L_{Aeq}
17 seconds measurement	63 dB L_{Aeq}
10 seconds measurement	63 dB L_{Aeq}
19 seconds measurement	62 dB L_{Aeq}

L_{Fmax} measured noise
2 metres from Windsave Turbine
by RMP Acoustics on 26 July 2007

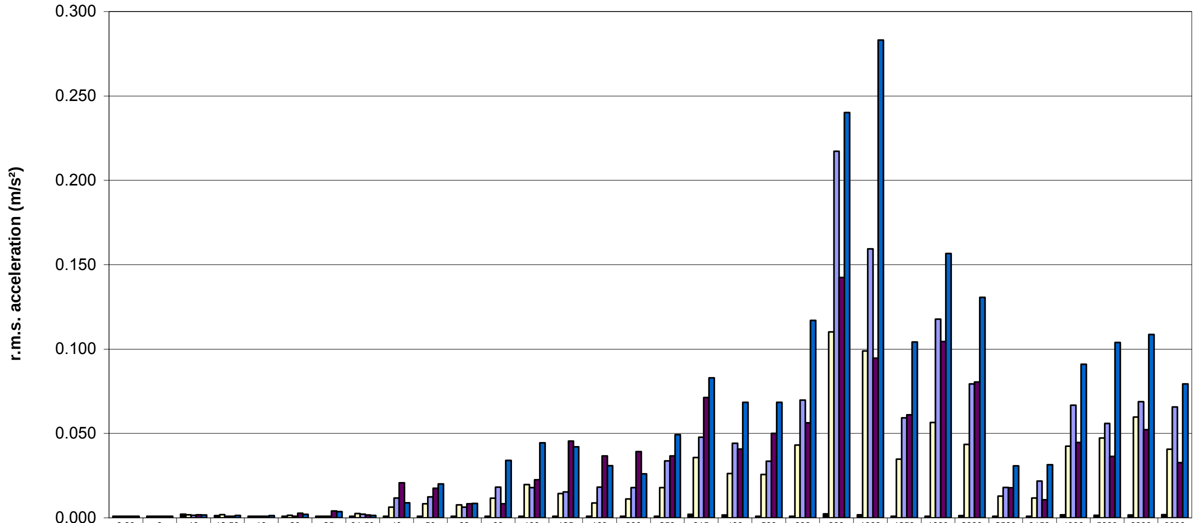


	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1k	1.25k	1.6k	2k	2.5k	3.15k	4k	5k	6.3k	8k	10k	12.5k	16k	20k
Static Turbine dB LFmax	66	65	63	65	61	62	58	56	54	52	52	50	51	49	48	49	50	46	44	42	40	39	37	34	32	28	25	21	17	17
17 secs dB LFmax	65	63	62	60	61	60	55	54	54	49	50	49	51	50	49	50	52	54	55	57	58	57	55	54	51	45	40	35	28	24
10 secs dB LFmax	64	61	63	63	62	61	61	59	62	57	55	54	55	53	52	52	53	52	54	55	57	58	56	55	54	48	42	36	33	27
19 secs dB LFmax	78	74	72	74	68	64	65	63	63	58	55	53	53	56	52	55	56	55	54	55	56	56	53	53	57	57	52	42	36	30

1/3 Octave Band Centre Frequency (Hz)

Static Turbine (background)	55 dB L_{AFmax}
17 seconds measurement	65 dB L_{AFmax}
10 seconds measurement	66 dB L_{AFmax}
19 seconds measurement	70 dB L_{AFmax}

**Measured vibration (horizontal axis)
on Windsave Turbine mounting to building
by RMP Acoustics on 26 July 2007**



	6.30	8	10	12.50	16	20	25	31.50	40	50	63	80	100	125	160
Static Turbine accel. (m/s²)	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
10 secs accel. (m/s²)	0.001	0.001	0.002	0.002	0.001	0.002	0.001	0.003	0.006	0.008	0.008	0.012	0.020	0.014	0.009
25 secs accel. (m/s²)	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.012	0.012	0.006	0.018	0.018	0.015	0.018
11 secs accel. (m/s²)	0.001	0.001	0.002	0.001	0.001	0.003	0.004	0.002	0.021	0.018	0.008	0.008	0.023	0.045	0.037
19 secs accel. (m/s²)	0.001	0.001	0.002	0.001	0.001	0.002	0.004	0.001	0.009	0.020	0.009	0.034	0.044	0.042	0.031

	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
Static Turbine accel. (m/s²)	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002
10 secs accel. (m/s²)	0.011	0.018	0.036	0.026	0.026	0.043	0.110	0.099	0.035	0.056	0.044	0.013	0.012	0.042	0.047	0.060	0.041
25 secs accel. (m/s²)	0.018	0.034	0.048	0.044	0.034	0.070	0.217	0.159	0.059	0.118	0.079	0.018	0.022	0.067	0.056	0.069	0.066
11 secs accel. (m/s²)	0.039	0.037	0.071	0.041	0.050	0.056	0.142	0.095	0.061	0.104	0.080	0.018	0.011	0.045	0.036	0.052	0.033
19 secs accel. (m/s²)	0.026	0.049	0.083	0.068	0.068	0.117	0.240	0.283	0.104	0.157	0.131	0.031	0.032	0.091	0.104	0.109	0.079

1/3 Octave Band Centre Frequency (Hz)

The following 2 sets of noise and vibration measurements were simultaneous:

10 seconds: 2nd noise measurement in graph
1st vibration measurement in graph

19 seconds: 3rd noise measurement in graph
4th vibration measurement in graph

Annex D British, European & International standards

Measurement & test standards for specific building services plant	
BS 848-2.6:2000 ISO 10302:1996	Fans for general purposes. Methods of noise testing. Airborne noise emitted by small air-moving devices. Section 6: Airborne noise emitted by small air-moving devices
BS EN 1151-2:2006	Pumps. Rotodynamic pumps. Circulation pumps having a rated power input not exceeding 200 W for heating installations and domestic hot water installations. Noise test code (vibro-acoustics) for measuring structure and fluid-borne noise
BS EN 1567:2000	Building valves. Water pressure reducing valves and combination water reducing valves. Requirements and tests
BS EN ISO 1680:2000	Acoustics. Test code for the measurement of airborne noise emitted by rotating electrical machinery
BS EN ISO 2151:2004	Acoustics. Noise test code for compressors and vacuum pumps. Engineering method (Grade 2)
BS EN ISO 3822-1:1999	Acoustics. Laboratory tests on noise emission from appliances and equipment used in water supply installations. Method of measurement
BS EN ISO 3822-2:1996	Acoustics. Laboratory tests on noise emission from appliances and equipment used in water supply installations. Mounting and operating conditions for draw-off taps and mixing valves
BS EN ISO 3822-3:1997	Acoustics. Laboratory tests on noise emission from appliances and equipment used in water supply installations. Mounting and operating conditions for in-line valves and appliances
BS EN ISO 3822-4:1997	Acoustics. Laboratory tests on noise emission from appliances and equipment used in water supply installations. Mounting and operating conditions for special appliances
BS 4954-2:1978	Methods for testing and rating induction units for air distribution systems. Acoustic testing and rating
BS EN ISO 5135:1999	Acoustics. Determination of sound power levels of noise from air-terminal devices, air-terminal units, dampers and valves by measurement in a reverberation room
BS EN ISO 5136:2003 BS 848-2.5:2003	Acoustics. Determination of sound power radiated into a duct by fans and other air-moving devices. In-duct method
BS 5944-1:1992 ISO 4412-1:1991	Measurement of airborne noise from hydraulic fluid power systems and components. Method of test for pumps
BS 5944-2:1992 ISO 4412-2:1991	Measurement of airborne noise from hydraulic fluid power systems and components. Method of test for motors
BS 5944-4:1984	Measurement of airborne noise from hydraulic fluid power systems and components. Method of determining sound power levels from valves controlling flow and pressure
BS 5944-5:1985	Measurement of airborne noise from hydraulic fluid power systems and components. Simplified method of determining sound power levels from pumps using an anechoic chamber
BS 5944-6:1992 ISO 4412-3:1991	Measurement of airborne noise from hydraulic fluid power systems and components. Method of test for pumps using a parallelepiped microphone array

BS ISO 6798:1995	Reciprocating internal combustion engines. Measurement of emitted airborne noise. Engineering method and survey method
BS 6880-1:1988	Code of practice for low temperature hot water heating systems of output greater than 45 kW. Fundamental and design considerations
BS EN ISO 7235:2003	Acoustics. Laboratory measurement procedures for ducted silencers and air-terminal units. Insertion loss, flow noise and total pressure loss
BS 7698-10:1999 ISO 8528-10:1998	Reciprocating internal combustion engine driven alternating current generating sets. Measurement of airborne noise by the enveloping surface method
DD ENV 12102:1996	Air conditioners, heat pumps and dehumidifiers with electrically driven compressors. Measurement of airborne noise. Determination of the sound power level
Draft EN 12102 (05/30138982 DC)	Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling. Measurement of airborne noise. Determination of the sound power level
BS EN 12736:2001	Electrically propelled road vehicles. Airborne acoustical noise of vehicle during charging with on-board chargers. Determination of sound power level
BS EN 13141-1:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Externally and internally mounted air transfer devices
BS EN 13141-2:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Exhaust and supply air terminal devices
BS EN 13141-3:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Range hoods for residential use
BS EN 13141-4:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Fans used in residential ventilation systems
BS EN 13141-5:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Cowls and roof outlet terminal devices
BS EN 13141-6:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Exhaust ventilation system packages used in a single dwelling
BS EN 13141-7:2004	Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings
BS EN 13141-8:2006	Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of un-ducted mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for a single room
BS ISO 13332:2000	Reciprocating internal combustion engines. Test code for the measurement of structure-borne noise emitted from high-speed and medium-speed reciprocating internal combustion engines measured at the engine feet
BS EN 13487:2003	Heat exchangers. Forced convection air cooled refrigerant condensers and dry coolers. Sound measurement
BS EN 14366:2004	Laboratory measurement of noise from waste water installations
BS EN 15036-1:2006	Heating boilers. Test regulations for airborne noise emissions from heat generators. Airborne noise emissions from heat generators
BS EN 15036-2:2006	Heating boilers. Test regulations for airborne noise emissions from heat generators. Flue gas noise emissions at the outlet of the heat generator

BS EN 60076-10:2001 IEC 60076-10:2001	Power transformers. Determination of sound levels
BS EN 60704-2-2:1995 IEC 60704-2-2:1985	Test code for the determination of airborne acoustical noise emitted by household and similar electrical appliances. Particular requirements. Forced draught convection heaters
BS EN 60704-2-5:2005	Household and similar electrical appliances. Test code for the determination of airborne acoustical noise. Particular requirements for electric thermal storage room heaters
BS EN 60704-2-7:1998	Test code for the determination of airborne acoustical noise emitted by household and similar electrical appliances. Particular requirements. Particular requirements for fans
BS EN 61400-11:2003	Wind turbine generator systems. Acoustic noise measurement techniques
DD IEC/TS 61400-14:2005	Wind turbines. Declaration of apparent sound power level and tonality values
Guidance & survey methods for insitu services noise	
BS 4142:1997	Method for rating industrial noise affecting mixed residential and industrial areas
BS 8233:1999	Sound insulation and noise reduction for buildings. Code of practice
BS EN ISO 10052:2004	Acoustics. Field measurements of airborne and impact sound insulation and of service equipment sound. Survey method
BS EN ISO 11203:1996	Acoustics. Noise emitted by machinery and equipment. Determination of emission sound pressure levels at a work station and at other specified positions from the sound power level
BS EN ISO 11205:2003	Acoustics. Noise emitted by machinery and equipment. Engineering method for the determination of emission sound pressure levels in situ at the work station and at other specified positions using sound intensity
BS EN ISO 11690-1:1997	Acoustics. Recommended practice for the design of low-noise workplaces containing machinery. Noise control strategies
BS EN ISO 11690-2:1997	Acoustics. Recommended practice for the design of low-noise workplaces containing machinery. Noise control measures
BS EN ISO 11690-3:1999	Acoustics. Recommended practice for the design of low-noise workplaces containing machinery. Sound propagation and noise prediction in workrooms
BS EN 14134:2004	Ventilation for buildings. Performance testing and installation checks of residential ventilation systems
BS EN ISO 14163:1998	Acoustics. Guidelines for noise control by silencers
prEN 15251 (05/30128995 DC)	Criteria for the indoor environment including thermal, indoor air quality, light and noise
BS EN 15657-1 (07/30161870 DC)	Acoustic properties of building elements and of buildings. Laboratory measurement of airborne and structure borne sound from building equipment. Part 1. Simplified cases where the equipment mobilities are much higher than the receiver mobilities, taking whirlpool baths as an example
BS ISO 15665:2003	Acoustics. Acoustic insulation for pipes, valves and flanges
BS EN ISO 16032:2004	Acoustics. Measurement of sound pressure level from service equipment in buildings. Engineering method