

Problems in residential design for ventilation and noise part 2: mechanical ventilation

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Introduction

Part 1 of this article described the design drivers and regulatory regime for noise and ventilation in dwellings through the Planning system and Building Regulations. This part discusses noise aspects of mechanical ventilation systems in dwellings. Mechanical ventilation is increasingly adopted to meet more onerous energy performance requirements, or to limit the potential for external noise ingress. General limits for internal ambient noise levels described in the World Health Organisations Guidelines for Community Noise (GCN)[1] are generally unsuitable for noise from mechanical services, as they are frequently too high to tolerate. Noise from mechanical ventilation systems is not currently regulated in the UK.

In the UK the industry for the design, supply, installation, commissioning and maintenance of domestic mechanical ventilation systems is currently in its infancy. Although the skills and expertise required to address all issues in every part of the supply chain are present and utilised for commercial buildings, they are rarely applied to dwellings. Failures in parts of the supply chain can result in excessive noise levels. Domestic mechanical ventilation systems have at times attracted bad press as if they are the cause of problems in buildings, when it has often been failures in the design, installation and commissioning that makes

them unsuitable to use.

With an industry currently unwilling to acknowledge the challenges of providing appropriate mechanical ventilation systems in dwellings and in the absence of regulation of noise levels, it is unsurprising that excessive noise frequently results. As the systems are usually under the control of the occupants, systems are generally operated at the level at which noise is tolerable – or turned off completely. As noted in part one of this article, the adverse impact of inadequate ventilation upon health and well-being is extensively documented as a public health problem and is not repeated here.

The ventilation requirements and conditions under Part F are described first. This article is based on the paper presented at the 2013 IOA Spring conference [2], with additional material that has subsequently become available.

Mechanical ventilation systems

Since 2002 one of the driving forces to improve standards of energy efficiency in national regulations has been European legislation [3]. The changes in standards have in turn led to the more extensive use of mechanical ventilation with heat recovery. As mechanical ventilation is inherently more controllable than natural ventilation, heat loss **P34 ▶**

P33 from uncontrolled ventilation through façade vents can be reduced. Mechanical ventilation with heat recovery brings increasing thermal performance benefits as the airtightness of the building envelope is increased [4]. Approved Document F (AD-F) describes two general Systems for compliance with the ventilation requirements using mechanical ventilation, System 3 and System 4, which are outlined below.

System 3 – Continuous mechanical extract (MEV)

This type of ventilation system extracts air from wet rooms (kitchens, bathrooms, utility rooms). The replacement air is either provided by means of background ventilators, or infiltration (air passing through the building envelope) may be relied upon where the design air permeability is greater than $5 \text{ m}^3 / (\text{h} \cdot \text{m}^2)$. The system can be either a centralised system, comprising a single fan ducted to extract from multiple rooms, or a decentralised system where individual fans extract air from each room. The systems have two ventilation rates, often referred to as “trickle” and “boost”. The minimum low rate or trickle rate must meet the minimum ventilation rates in Table 5.1b in AD-F, and the boost setting must meet those in Table 5.1a for continuous extract - minimum high rate. Systems may also have other settings for user comfort purposes. Purge ventilation may be provided by opening windows.

System 4 – Continuous mechanical supply and extract with heat recovery (MVHR)

Air is extracted through ducts from wet rooms. The extracted air passes through a heat exchanger before being exhausted to outside. Incoming fresh air is pre-heated as it passes through the heat exchanger before being supplied to habitable rooms such as living rooms and bedrooms. The systems in AD-F have two ventilation rates - trickle and boost, and must meet the same minimum ventilation rates for each state as MEV, although again other systems settings may be provided for user comfort and control. Purge ventilation may be provided by opening windows. Background ventilators are not required.

Noise aspects of ventilation conditions

For Systems 3 and 4, AD-F provides for two controlled ventilation conditions as well as purge ventilation in order to address the various demands imposed by occupation. The noise aspects of the two controlled ventilation conditions are discussed below.

Whole dwelling ventilation

Whole dwelling ventilation is the minimum ventilation required continuously while the dwelling is occupied; it would seem entirely appropriate to achieve appropriate indoor ambient noise level limits under this ventilation condition. Appropriate noise level limits are discussed below. It is proposed that this should be the minimum ventilation requirement associated with limits for noise from mechanical services. In practice, mechanical systems may have more operational set points that are controllable by the users than those conditions required for compliance with AD-F. While it is desirable for the occupants that noise levels are satisfactory for all continuous whole-dwelling ventilation rates they may select, this may be the consideration of the designers rather than of regulation.

Control of humidity in bathrooms and kitchens

For the control of humidity from bathrooms, kitchens and utility rooms, extract ventilation rates are lower for Systems 3 and 4 that provide whole dwelling ventilation continuously, compared with intermittent extract rates required for ventilation provided with System 1. Minimum wet room intermittent extract rates for System 3 and 4 are described as the “minimum high rate” in AD-F, and often referred to as “boost” ventilation. Depending on the whole dwelling ventilation rate and dwelling requirements, the boost ventilation rate may be no higher or only marginally higher than the whole dwelling ventilation rates in any case; they are generally of the same order of magnitude. Some informative research is discussed in later sections concerning the boost rate for mechanical extract, but more research is needed to inform acceptable noise limits for this ventilating condition.

Purge ventilation

Even where whole dwelling ventilation is provided by mechanical means, the most common means of providing purge ventilation is via opening windows. Noise considerations of purge ventilation provided in this

manner are discussed in Part 1 of this article. As provision of purge ventilation by mechanical means is rare, no discussion of the noise aspects of this subject has been identified in the literature. It would seem that higher noise levels than those required for continuous operation are likely to be acceptable to occupants, but identification of particular levels is not currently possible.

Purge ventilation and overheating

It should be noted that a common use of purge ventilation is to assist in the provision of thermal comfort by reducing the potential for overheating. Whilst this may be convenient and practical, in terms of compliance with the Building Regulations it is a benefit but not the primary purpose of purge ventilation. Overheating is not currently controlled under the Building Regulations. The ventilation rates required to control overheating may be determined for a particular design; there is no reason why the ventilation rates identified for purge ventilation in AD-F should also be the same ventilation rate to control overheating.

Overheating is currently the subject of much analysis, research, definition, and attempted mitigation in some circumstances; enhancing thermal comfort may be achieved in a variety of ways, and relying on purge ventilation provided by opening windows is not always suitable. High external noise levels have been cited [23] as a reason that occupants are reluctant to open windows to provide higher natural ventilation rates during hot weather, when various degrees of elevated temperatures may result. However, the balance between occupants' preferences between various degrees of elevated temperature compared with elevated noise levels has not been documented in the literature, and can only be subject to speculation. Further research is urgently needed to better inform this area of indoor environmental quality where the balance between environmental factors is under the control of the occupants.

Requirement to limit noise levels in dwellings

Requirements to control noise levels in new dwellings may be described in planning conditions, generally where environmental health officers identify external noise as being a concern, but not typically to identify mechanical services noise specifically. Employers or developers occasionally include a performance requirement for noise levels from mechanical services; although this would be normal practice in a commercial development, it is not yet so for new dwellings.

AD-F refers to BS 8233 and recommends, but does not require, that noise levels do not exceed 30 dB(A) in bedrooms and living rooms when a mechanical system is running on its minimum low rate. AD-F also suggests that noise levels should be lower; this consideration is discussed in more detail later. As a recommendation the noise criteria in AD-F are not regulated. Part E of the Building Regulations governing the Resistance to the Passage of Sound, described in Approved Document E (AD-E) does not address the penetration of mechanical services noise into habitable spaces. Until the appropriate place for legislation to control these aspects is determined, LPAs could regulate noise from mechanical services with a planning condition exactly as for external noise ingress.

Awareness of the issues associated with the provision of mechanical ventilation and noise pre-date the larger scale adoption of the technology over the last decade, although it would appear that the pitfalls that have been identified historically may not have been widely considered. For instance, in the Netherlands, the more recent, widespread and increasing use of mechanical ventilation has led to much controversy [6, 10] which could no doubt have been avoided had the lessons been heeded. To date the implications of mechanical ventilation have been more thoroughly reviewed in other countries, and that research is discussed below.

Problems with System 3, MEV

With MEV, as noted previously, building leakage may be relied upon for make up air, but this relies upon assumptions about both the design and as-built air permeability. It may be considered prudent and appropriate at the design stage to include trickle vents providing an effective area of $2,500 \text{ mm}^2$ in each habitable room, such that the design may be suitable for buildings of all air permeabilities.

Inclusion of a typical trickle vent of $2,500 \text{ mm}^2$ effective area into the bedrooms in the examples in Appendix C of AD-F is calculated to result in a sound level difference of 28 dB for the ground floor flat (example C1), and 26 dB for the smaller bedroom in example C3. These values are still less than the calculated level difference due to standard glazing; 

however, when only one vent is required, it is usually practical and feasible to use “acoustic” trickle vents, and hence achieve greater attenuation as required to control external noise ingress. It is therefore relatively straightforward to carry out the façade sound insulation design if System 3 is adopted.

This ventilation strategy may also present the lowest level of acoustic risk for designers as extract is typically made from rooms that are not noise sensitive i.e. bathrooms and kitchens; however, MEV still requires coordinated consideration by the design team. Balvers et al [6] reported in 2012 that in 67 % of cases ventilation units were located in positions that increased the chances of ventilation noise; positions cited include a built-in cupboard in a bedroom, or on a lightweight wall without proper vibration control. The location of the ventilation unit, or ventilation units in the case of decentralised systems, is therefore an issue that needs to be addressed in order to mitigate noise related concerns. At a time when noise levels were not regulated in the Netherlands, noise levels exceeded 30 dB(A) in 54 % of living rooms and 21 % of bedrooms when MEV was employed.

Stevenson et al [18] note excessive noise arising from poor ductwork in MEV systems on a small development that they studied. In order to control noise levels occupants were reported to have the habit of keeping the MEV ventilation rate low. The non-acoustic drawbacks of MEV relate to energy use and comfort; the fans used to establish air flow require energy, hence the appeal of MVHR.

Problems with System 4, MVHR

In a 1997 Swiss study, Dorer et al [7] suggested that noise levels should be evaluated in comparison to the background noise, as historically ventilation systems had been based on natural systems without mechanical noise. Although this may not generally be practical, those researchers also concluded that sound levels according to the Swiss standards of the time for system noise, 30 to 35 dB(A), were too high, and that acceptable ventilation system noise should be limited to 20 - 25 dB(A).

In another 1997 study, Veld et al [8] considered that the acceptance and appreciation of ventilation systems is mainly determined by the perceived indoor air quality, thermal comfort and noise. System generated noise, and cross-talk through ventilation ducts between rooms were both noted. In particular, it was remarked that noise relating to the ventilation system and components can result in users turning off the ventilation system or closing vents; actions that have a correspondingly negative influence on ventilation and indoor air quality.

Alexander et al [16] reported at the turn of the millennium on a UK study of 50 low-energy rental dwellings; they encountered criticisms relating to noise and established that noise was one of the main reasons for switching back to “normal” ventilation (presumed to mean natural ventilation). Macintosh and Steemers [17] reported in 2005 on a study of 58 urban UK homes with MVHR systems. Complaints by occupants about noise from the inlets were observed. A limited number of sound level measurements were undertaken with windows both open and closed. It was remarked that in one case, the ventilation system was almost as noisy as having a window open. In these studies systematic measurements of noise levels were not made, so that the comments can only be interpreted qualitatively. In 2002 Concannon [20] noted that noise levels from

mechanical systems of 30 to 45 dB(A) are typical in single-family dwellings if no sound reduction measures are present.

In 2007 Kurnitski [9] reported on a Finnish study of 102 newly built houses. He concluded that only 57 % of the dwellings were capable of complying with the ventilation regulations of 0.5 ach with a noise level in living rooms and bedrooms not exceeding 28 dB(A). Complaints about ventilation noise were found to correlate best with the maximum noise level in bedrooms when the ventilation system was operated at its maximum fan speed, the boost setting. The as-used average sound pressure level, including background noise, was recorded to be 22 dB(A); cases of noise levels as low as 17 and 18 dB(A) were recorded. Measurement periods with a background noise level below 20 dB(A) were available in all houses. Systems were generally operated at the level at which noise was tolerable, despite the ventilation rate potentially being inadequate at those settings. Noise levels up to 30 dB(A) were described as “too noisy” by more than 40 % of respondents.

In 2008, Hasselaar [10] inspected 500 homes with measurements and occupant interviews. He noted that noise of fans limits the occupiers’ use of higher set points for the required ventilation volumes, and the rooms became polluted as a result. Similarly, Hady et al [11] note from a survey of 100 homes that the noise level at the set point was so high that users operated systems at lower levels, and significant adverse health effects were the result of insufficient ventilation.

Many of these findings were identified again by Balvers et al [6] in 2012, following surveys of 299 homes in the Netherlands. At the time of the study noise levels were unregulated. With the mechanical systems set to provide the required flow rates (or highest possible where they did not comply), noise levels exceeded 30 dB(A) in one or more bedrooms in 86 % of homes with MVHR. The ventilation unit was considered to be in an inappropriate place, such as in a bedroom cupboard, in 53 % of homes; and silencers were not properly installed on either the supply or exhaust ducts in 66 % of cases. Not surprisingly, most users do not operate ventilation systems as recommended for air flow rates because of high noise levels. In 2012, the Dutch introduced a regulation to limit noise at 30 dB(A) from mechanical ventilation systems in living rooms and bedrooms.

A recent report on MVHR systems in Code for Sustainable Homes level 6 dwellings in the UK has been published [24]. Initially, noise resulted in the MVHR system being listed in the occupant surveys as one of the ‘worst things about the house’. The MVHR fan units installed in the homes were running at close to maximum fan speed; this resulted in the systems being very noisy, which was noticed and annoying to nearly all the occupants. It was considered necessary to intervene in the monitoring after 12 months to recommission all 10 systems and replace some of the components, including the fan unit in one case. Changes were also made to air valves, and noise levels were significantly reduced as part of the recommissioning. A focus group revealed that the reduction in noise from the MVHR system was listed as one of the best things about the homes since the previous survey. The recommissioning by the Building Research Establishment allowed the MVHR system to be slowed and the noise levels reduced for most homes to within the CIBSE guidelines of NR 30 for living rooms, and NR 25 for bedrooms. The improvement was noted as being very significant and resulted in the occupants commenting that they could hardly hear the fan units running. The report concludes **P36**

P35 that the CIBSE guideline figures provide a good basis for acoustic design of these products in energy efficient homes, although appropriate levels are discussed further below.

Causes of excessive noise

The following list of issues are all taken from actual findings on investigations that have been reported. Issues that can lead to excessive noise for occupants are noted under the following headings of design, installation, commissioning and maintenance.

Design issues

- Centralised MEV or MVHR unit located in inappropriate place for break out or structure borne noise, e.g. bedroom cupboard or on rafters in loft above a bedroom.
- Poor ductwork layout – too many bends can lead to additional fan pressure requirement and regenerated noise
- Specification of flexible ductwork
- Inadequate attenuation of duct borne noise
- Installation issues
- Ductwork kinked or damaged inhibiting flow
- Ducts not connected up to supply or extract valves (which will inhibit flow and require higher fan setting)
- Wrong type of outlet fitted (using extract outlets for supply air can lead to regenerated noise)
- No anti-vibration mounts used
- Failure to ensure ductwork is clean when installed prior to commissioning
- Use of flexible ductwork where not specified

Commissioning issues

- The standard practice of commissioning with non-compensating flow measurement devices means that flows are not generally well balanced or indeed correctly set.

Maintenance issues

- Failure to replace filters at appropriate intervals (the market for replacement filters clearly indicates that very few users replace filters at appropriate intervals)

Appropriate noise limits

Detailed Finnish study

Kurnitski et al [9] undertook a survey examining the dependency between the maximum noise level in bedrooms and ventilation noise complaints. An upper limit threshold of 22 dB(A) resulted in < 10 % complaints and an upper limit threshold of 25 dB(A) resulted in < 20 % complaints. Based upon this same research a significant dependency was found between the maximum fan speed of the ventilation unit (boost mode) and complaints, rather than the whole dwelling ventilation rate. Under this scenario complaints of < 20 % could be associated with the boost condition with the consequence that, at the continuous extract minimum low rate (as AD-F), the number of complaints for the majority of time would fall nearer to, or within, the < 10 % threshold. UK research is required to determine if attitudes are similar.

Suitable noise metric

Building services noise levels well below 30 dB(A) are clearly necessary for user acceptance in many instances. The A-weighted scale may not be the most appropriate metric for such noise levels, as the loudness of the lower frequency components at these lower levels is under-represented. Researchers have correlated annoyance of building services noise with other metrics in an office scenario [22], but no similar association in a domestic situation where noise levels are lower is known.

European guidance and standards

Some European countries have standards and guidance for noise from building services. For example, Finnish guidance [19] published in 2008 requires that noise from HVAC systems in residential rooms does not exceed 28 dB(A), with a limit of 24 dB(A) for a better quality indoor environment. For all standards of internal environment, noise levels in kitchens must not exceed 33 dB(A). The standard for certified PassivHaus dwellings [13] is a limit of 25 dB(A) in both living rooms and bedrooms. For all residential building services, not just that using MVHR, BS EN 15251 [12] recommends a living room design range of 25 to 40 dB(A) with

a default design value 32 dB(A) and a bedroom design range of 20 to 35 dB(A) with a default design value 26 dB(A). This guidance is perhaps superseded by the recent Cost Action described below.

COST Action TU0901

The recently concluded programme for European harmonisation of acoustic descriptors [25] has included the determination of Classes for noise from building services. The proposed classes are shown in Table 1.

This does not distinguish between different room types, and has much lower limits for the highest performance, Class A than may be anticipated by designers in the UK. The information about classes suggests occupant

Type of space and source	Class / Leq ,dB(A), and dissatisfaction, %				
	A	B	C	D	E
Rooms in dwellings; ventilation / heating installation	≤ 20	≤ 24	≤ 28	≤ 32	≤ 36
Occupant dissatisfaction	≤ 5 %	≤ 10 %	≈ 20 %	≈ 40 %	≥ 60 %

Table 1: Class limits for service equipment noise proposed in COST Action 0901

dissatisfaction levels as shown in Table 1 with around 20 % dissatisfaction for noise levels not exceeding 28 dB(A). On this basis it may be suggested that Class C should be the lowest class to which it is appropriate to build new dwellings, equivalent to a limit of 28 dB(A) in all rooms, if 20 % occupant dissatisfaction is acceptable.

Commissioning

Although the noise issues relating to mechanical ventilation have not been extensively researched in the UK, deficiencies in air flow rates are already widespread [5, 21], despite the requirement in the 2010 Part F for commissioning to be undertaken by a “competent person”. The experience of the acoustic consulting industry clearly demonstrates that if a particular level of acoustic performance is sought, there needs to be a robust commissioning regime to ensure its implementation. The message from the above literature review of more than 1,000 homes is clear, and has been found on numerous occasions in multiple countries: if noise levels from mechanical systems are not regulated, they are generally excessive and consequently many people opt to live with inadequate ventilation and risk the associated health effects, rather than tolerate excessive noise levels.

No doubt acousticians would agree that commissioning checks on performance are only effective if there is also a requirement for the person carrying out the measurements to be independently accredited by a third party, to ensure consistency and to mitigate potential pressure brought to bear on the tester by the contractor. Testing on completion is risky for contractors; they need to be able to effectively manage the risk, which would mean that systems would need to be appropriately designed and constructed. In our experience, commissioning measurements are very seldom required by clients in dwellings, no doubt at least in part because the risk of excessive noise levels is not widely understood.

The authors' recent experience includes measurements of MVHR installations for which the units have not even been tested for noise emissions as described in BS EN 13141 [15]; suppliers of MVHR systems can lack the knowledge and expertise to design appropriate noise control measures even where data is available.

Unless domestic mechanical noise levels are included within the regulatory framework, and are backed up with commissioning requirements, it is likely that no regard will be given to them. It is suggested that there could be a requirement in AD-F to control noise to suitable levels along with adequate flow rates. Until regulation of noise from mechanical services becomes a statutory duty, LPAs could also regularly stipulate the need for commissioning noise measurements for MEV and MVHR to demonstrate that adequate conditions have been achieved, whether or not external noise is an issue for those sites.

Conclusion

A common reason of occupant mis-operation of mechanical 

ventilation systems is noise. If these systems are to be acceptable and used appropriately, it is imperative the noise emissions are regulated, and that the commissioning requires both airflow and noise levels measured by organisations with third party accreditation. It has been noted that AD-F, referring to BS 8233, recommends that noise levels from mechanical systems, when providing ventilation at the whole dwelling ventilation rate, do not exceed 30 dB(A) in bedrooms. The literature review above however suggests that this may be intolerable to a significant proportion of people. More UK specific research is needed to confirm appropriate upper limits; it is suggested that the BS EN 15251 default value of 26 dB(A) for bedrooms may be used in the absence of more informed levels, although this bedroom level may result in complaints from more than 20 % of occupants. Similarly, a limit of 28 dB(A) for living rooms is indicated in the COST Action as the likely limit for 20 % dissatisfaction.

Evidence suggests that it may be more appropriate for the upper limit threshold to relate to the continuous extract, minimum high rate (boost) rather than the minimum whole dwelling ventilation rate, as currently proposed by AD-F. Further UK specific research is required to determine suitable noise limit levels for boost ventilation rates from MEV and MVHR. Further UK specific research is also required into acceptable noise levels for the provision of purge ventilation from mechanical services, or higher ventilation rates as required to control overheating; owing to the complete lack of data it is suggested that this may be temporarily excluded from consideration within the design.

It is considered that Part F of the Building Regulations may be the appropriate place to provide statutory noise limits, and a requirement for commissioning noise measurements from mechanical services. In the meantime, LPAs could stipulate noise limits from mechanical systems within dwellings when there are no external noise issues identified. Greater coordination between the Approved Documents and technical guidance to accompany the NPPF is considered essential. It is suggested that the gap between LPAs and Building Control may be bridged if planning conditions refer to a "scheme of acoustic design to enable appropriate internal ambient noise levels to be achieved whilst ventilation is provided at the minimum whole building ventilation rate as described in

Approved Document F". This type of condition would cover both natural and mechanical systems, depending on what is employed on a particular development, and enable separate limits for each. A requirement for commissioning measurements is considered appropriate in all cases. **P38**

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