Noise and ventilation in dwellings:

Problems and opportunities

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Summary

Classes of noise levels in dwellings are described in COST Action TU0901 without concurrent quantification of other indoor environmental quality measures such as air quality or thermal comfort. The modern trend towards energy efficient buildings means that new dwellings must be more air tight than previously, and better thermally insulated. Having an appropriate ventilation strategy is vital to ensure adequate air quality, and requires ventilating at different rates during different activities. Thermal comfort may be managed by a variety of means, including the specification of appropriate building fabric, the intermittent use of natural ventilation and/or mechanical services.

There is little research or guidance available on integrating different ventilation rate requirements with acceptable noise conditions. This paper describes four difficulties in the design of dwellings in England for assessing ventilation system operation with acoustic conditions. The first problem is insufficient qualification of the ventilation conditions that should be achieved while meeting the internal noise limits. Ventilation strategies and noise limits are assessed by separate bodies which assess each requirement separately.

The second problem is the feasibility of "natural" ventilation strategies with controllable background ventilators (trickle vents); the quantity of trickle vents required is often not practical to incorporate in flats, especially if they have one external façade. The third problem concerns noise from mechanical ventilation systems that is not controlled under English Building Regulations. Surveys including over 1000 dwellings are reviewed; typical failings that can lead to excessive noise are identified in the design, procurement, installation, commissioning and maintenance of these systems. The fourth problem concerns the assessment thermal comfort and acoustic conditions in summer. Emerging definitions of overheating are described, and the potential to consider with acoustic conditions is discussed.

The development of the COST TU0901 Acoustic Classification Scheme into an ISO Standard presents an opportunity to associate the classification of noise levels with an appropriate ventilation condition.

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1. Introduction

COST Action TU0901 [1] introduces Classes for noise levels in dwellings from both general external sources and service equipment. The adverse effects of noise on residents are well known; preferred limits for internal ambient noise levels are described in the World Health Organisation Guidelines for Community Noise (GCN) [2], the Night Noise Guidelines (NNG) [3], and various national Standards. The adverse impact of inadequate ventilation upon health and well-being is extensively documented [4-11]. Insufficient ventilation can also lead to adverse effects on the building fabric, and there are instances of mould growth in modern dwellings which once again can impact upon health and well-being. Standards for noise levels in dwellings generally do not qualify the ventilation condition that should be achieved with the noise levels. Consideration of thermal comfort (over heating) in conjunction with noise levels is currently more problematic as suitable definitions are only just being established.

In England, Part F of the Building Regulations requires that there shall be adequate means of ventilation provided for people in the building; Approved Document F (AD-F) describes the meaning of “adequate”. As new buildings have become more airtight [12] over recent years, the importance of, and requirement for, adequate provision of controlled ventilation has changed significantly. Although AD-F makes reference to specific noise standards, noise levels are not regulated with ventilation provision.

Since 2002 one of the driving forces to improve standards of energy efficiency in National regulations has been European legislation [13]. The changes in standards have in turn lead to the more extensive use of mechanical ventilation with heat recovery. As mechanical ventilation is inherently more controllable than natural ventilation, heat loss from uncontrolled ventilation through façade vents can be reduced.

This paper addresses four broad problems in residential design for achieving ventilation provision with reasonable internal ambient noise levels. The problems are for the residents who will occupy these buildings, rather than for any particular group of designers.

2. Background

Requirements to limit noise levels in new dwellings are described in planning conditions. The first problem identified is due to insufficient or inappropriate qualification of the ventilation conditions that should be achieved while meeting the internal ambient noise level limits.

The second problem is with the practical provision of natural ventilation in new dwellings. While noise limits may be required by planning conditions, ventilation provision is regulated by the Building Control Body (BCB). The BCB may permit opening windows for ventilation, while the response to the planning condition assesses noise levels with windows closed, or a lesser provision of ventilation than required under Part F of the Building Regulations. This problem has become more widespread as the required provision of trickle vents has increased between subsequent editions of Approved Document F between 2000, 2006 and 2010 to the point where it is practically unfeasible in many dwellings.

The third problem is noise from mechanical ventilation provision. Mechanical ventilation is increasingly adopted to meet more onerous energy performance requirements, or to limit the potential for external noise ingress. 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.

The fourth problem concerns the assessment thermal comfort and acoustic conditions in summer. Emerging definitions of overheating are described, and the potential to consider with acoustic conditions is discussed.

The problems identified in this article result in new dwellings currently being built that do not enable residents to enjoy reasonable internal air quality and noise levels simultaneously, or reasonable thermal conditions and noise levels. The ventilation requirements and conditions required in England under Part F are described first. Analysis and discussion of natural ventilation provision is then described. The various modes of operation of mechanical ventilation systems is then discussed, along with the current state of the industry in England.

3. Ventilation requirements

Ventilation is the supply and removal of air from a building. AD-F notes that ventilation is required to provide outside air for breathing, to dilute and remove pollutants in the air, including odours, and to control excess humidity, particularly in rooms such as bathrooms and kitchens.

AD-F identifies three distinct ventilation conditions:
Whole building / dwelling ventilation - provided continuously when occupied.
Extract ventilation from wet rooms - provided intermittently when required.
Purge ventilation - provided throughout the dwelling, intermittently.

The provision of "adequate ventilation" includes meeting all these requirements at different times. Ventilation air may also be used as a means to cool buildings – i.e. to assist in the provision of thermal comfort, but this is not controlled under AD-F.

Overheating is an increasing problem in new buildings, and becomes highlighted during heat waves. For buildings in use, using natural ventilation is typically the default - and may be the only practical - strategy to control overheating. The acoustic conditions while attempting to control overheating with natural ventilation is not often considered.

AD-F offers a method for compliance with the air quality criteria by the adoption of a ventilation *System*. AD-F describes four types of ventilation Systems for dwellings, summarised below.

3.1 System 1 – Background vents with intermittent extract

Background ventilators are considered to provide whole dwelling ventilation; this is then supplemented by intermittent mechanical extract from wet rooms (such as kitchens, bathrooms and utility rooms). Purge ventilation is generally provided by opening windows. System 1 is often the default ventilation strategy, bearing most resemblance to traditionally established systems and expectations.

3.2 System 2 - Passive Stack Ventilation

This system comprises vertical ducts to roof terminals from wet rooms. Polluted air is drawn up the ducts by wind or stack effects. The replacement air is considered to be provided by means of background ventilators. This system is rarely used (see below), hence is not discussed further in this article.

3.3 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). 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.

3.4 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.

3.5 Popular ventilation Systems currently used in England

According to BSRIA, a survey [14] of dwellings constructed in 2011 to the 2010 Part F requirements found the breakdown between ventilation System types to be as shown in Table 1.

Table 1: Percentage mix of new build ventilation System types from a 2011 survey

AD-F System	Percentage of new dwellings adopting System type
1	30 %
2	0.5 %
3	40 %
4	29.5 %

3.6 Purge ventilation

The requirement for purge ventilation is in AD-F is described as:
"..to aid the removal of high concentrations of pollutants and water vapour released from occasional activities such as painting and decorating or accidental releases such as smoke from burnt food or spillage of water. Purge ventilation is intermittent, i.e. required only when such occasional activities occur."
There is guidance in AD-F for the provision of opening windows so as to allow for purge ventilation at a rate of 4 air changes / hour (4 ach). If not provided with opening windows, mechanical systems are presumed.

4. Noise aspects of natural ventilation

4.1 Whole dwelling ventilation

It would seem entirely appropriate to achieve indoor ambient noise level limits while providing whole dwelling ventilation, as this is required continuously while the dwelling is occupied. This should be the minimum requirement associated with limits for external noise ingress.

4.2 Control of humidity in wet rooms

For the control of humidity from bathrooms and kitchens, System 1 relies on fans providing intermittent extract ventilation. The intermittent extract rates required are similar to purge ventilation rates for those rooms. While high noise levels under intermittent extract conditions may be annoying and are reported anecdotally [15], no research of acceptable levels has been identified.

4.3 Purge ventilation and over heating

As for intermittent extract, tolerance of noise levels under purge ventilation conditions has not been widely researched and is not widely reported, although interactions have been noted between noise, air quality, thermal comfort and lighting [16].

Although thermal comfort is not addressed by AD-F, purge ventilation may be used to control overheating. Whilst the relationship between noise, temperature and comfort in a residential environment is not well explored some studies have been undertaken. Research by Santos and Gunnarsen revealed that a decrease in noise level of 7 dB gave the same decrease in annoyance as a 1^{o}C reduction in operative temperature [17]. Separately, Clausen et al. found that, within a temperature range of 23-29^{o}C, a 3.9 dB change in noise level had the same effect on comfort as a 1^{o}C change in operative temperature [18].

It is reasonable to suggest that purge ventilation and sleep may not be compatible as purge ventilation is intended to be intermittent and sleep is preferably taken continuously. Therefore if purge ventilation is necessary to control overheating, occupants may choose to sleep with the windows open overnight if the noise levels are tolerable.

The provision of purge ventilation (4 ach) may be considered by mechanical means using the same system components as for whole building ventilation. However, the purge ventilation rate is likely to be at least 8 times the whole dwelling ventilation rate which would result in fan noise increasing by many tens of decibels for this increase in flow, consequently the fan would need to be significantly oversized as compared to the whole building ventilation rate. The requirements for a mechanical system to provide the required purge flow while meeting the preferred noise level limits is not therefore considered to be particularly practical, sustainable or affordable.

More research is required to identify acceptable noise levels under purge ventilation conditions. These limits may be different for external noise ingress, if purge ventilation is provided with opening windows, or for noise from mechanical services. The role of purge ventilation in controlling overheating needs to be both qualified and quantified - to determine the actual ventilation rates required to control overheating to identified extents and to enable reasonable internal environmental quality. A means of mechanical cooling provision may be a necessary consequence of providing suitable standards of indoor environmental quality with ventilation and control of external noise ingress. Acoustic issues associated with mechanical cooling should therefore also be a consideration in the building services design.

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 [19] 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 for 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.

5. Requirement to limit noise levels in dwellings

In England, requirements to control external noise ingress into new dwellings are described in planning conditions, where planning departments identify external noise as being a concern. Some local authorities describe levels of external noise sufficient to warrant a planning condition in their local plans, others determine the requirement on a case by case basis, but there is no national policy or methodology.

Without a coordinated methodology and standard it is not possible to ensure consistent and appropriate environmental noise standards at a national level.

6. Details of natural ventilation provision

This section explores the constraints and limitations of providing trickle ventilators within dwellings. The general calculation method for the sound insulation provided by façade elements is described in BS EN 12354-3 [20]. The application of this Standard and manufacturers' literature for the sound insulation of their products is used in the assessment below. Six varieties of through-frame trickle vents of nominal 4000 mm^2 free area were tested [21] and shown to have a typical $D_{n,e,w}$ (C_{tr}) of 34 (-1) dB. The equivalent area of such vents is typically a little over 2,500 mm^2, for a unit length of between 400 and 500 mm. The sound insulation provided by various elements and partially open windows has been extensively researched and documented [21, 22]. The EU SCATS project [23] for example accepted that, at an open window, the noise attenuation is 10–15 dB. The example dwellings examined below have been taken from Appendix C of AD-F.

6.1 Ground floor flat example

The example in Appendix C of AD-F shows that in a single bedroom, ground floor flat of 36 m^2 floor area, the total equivalent area of background ventilators should be at least 35,000 mm^2. Such a dwelling may only have windows in the bedroom and living room. The total length of typical trickle vents required for the flat would be in the region of six or seven linear metres. This extent of window frame is unlikely to be available in a dwelling of this size. Disregarding these practicalities for the time being, based on typical through-frame slot vents, seven units may be required to provide the required equivalent area, and the sound level difference into the small bedroom in example C1 of AD-F is some 19 dB with standard trickle vents. If the night time internal level limit is 30 dB(A), this would limit external noise impact to no more than 49 dB(A) if this ventilation strategy is to be feasible. Such an external noise level would not traditionally be considered to be incompatible with a natural ventilation strategy.

In this same example dwelling, if the design air permeability is less than 5.0 m^3/m^2.hr, an additional 10,000 mm^2 of background ventilator effective area is required. This would increase provision to 45,000 mm^2, with consequential implications for sound insulation. Even more significantly, however, if the flat has a single exposed façade, the area of background vents determined from Table 5.2a is required at both low and high level within the façade - the area requirement is doubled. This would appear to offer increasingly few possibilities for natural ventilation without a bespoke ventilator design, as well as being practically unfeasible with background ventilators.

6.2 Semi-detached house example

Example C5 of AD-F shows that for a semi-detached house of 84 m^2 floor area, the total equivalent area of background ventilators should be at least 40,000 mm^2. With five habitable rooms and two wet rooms, let us assume 2,500 mm^2 equivalent area in the kitchen and bathroom, leaving 35,000 mm^2 required between the dining room, living room, and three bedrooms. Noting as above this would typically require three through frame trickle vents each around 450 mm long, in each habitable room.

Again disregarding practicalities, with three typical through-frame slot vents, the sound level difference into the small bedroom in the example of AD-F is some 21 dB. This may be compared with a typical sound level difference through 4-16-4 mm double glazing, assuming a window area that is 10 % of the floor area, of 31 dB for road traffic noise. Hence the limiting factor for the façade sound insulation is likely to be the ventilation detail and room volume, rather than the glazing.

7. Challenges in natural ventilation provision

The examples above illustrate how sensitive the façade sound insulation design is to the ventilation strategy, and how the background ventilator requirement is a function of not only the internal floor area and number of bedrooms, but also the design air permeability, the height of the dwelling above ground level and the number of exposed façades. The practicality of incorporating the number of background ventilators calculated is often unfeasible.

Evidence demonstrates that Building Control frequently accept that partially open windows may be relied upon for compliance with Part F, whether or not appropriate provision of background ventilators is made [15]; however, despite the merits of disregarding the guidance of AD-F, the ability of such a strategy to provide adequate ventilation is highly questionable, and clearly this undermines any façade sound insulation performance when ventilation is provided.

Building Control and Planning are separate functions; there is generally no coordination between them - so that the means of compliance with Building Regulations is of no concern to the LPA. The LPA may be satisfied that façade sound insulation is achieved with suitable glazing and perhaps one or two trickle vents (depending on their views), while Building Control may simultaneously consider that opening windows may be required to provide the ventilation. The occupants may therefore choose suitable internal noise levels or adequate ventilation, but not both.

Meeting the requirement for background ventilators is typically the most significant constraint in controlling external noise ingress into small rooms, thereby limiting the potential for using System 1. “Acoustic” trickle vents are widely available, and can provide higher levels of attenuation, however the acoustic attenuation also often typically reduces the airflow performance, and lower effective areas are achieved with larger units. Effective acoustic designs tend to be so much larger than “standard” type vents that it is entirely impractical to incorporate the effective areas calculated into the façade. Bespoke natural ventilation design solutions are available from a few manufacturers, but the impact on the façade is generally significant; this requires a commitment from the developer and architect early in the design process to adopt these solutions.

8. Noise aspects of mechanical 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.

8.1 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.

8.2 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.

8.3 Purge ventilation

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

8.4 Requirement to limit mechanical services noise levels in dwellings

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.

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 lead to much controversy [24, 25] 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.

8.5 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 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 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 [24] 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 light weight 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 [26] 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.

8.6 Problems with System 4, MVHR

In a 1997 Swiss study, Dorer et al [27] 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 [28] 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 [29] 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 [30] 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 [31] 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 [32] 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 [25] 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 [33] 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 [24] 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 [34]. 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 ten 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 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.

8.7 Causes of excessive noise

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

8.8 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

8.9 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

8.10 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.

8.11 Maintenance issues

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

9. Appropriate noise limits

Kurnitski et al [32] 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.

9.1 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 [35], but no similar association in a domestic situation where noise levels are lower is known.

9.2 European guidance and Standards

Some Europeans countries have standards and guidance for noise from building services. For example, Finnish guidance [36] 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 [37] 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 [38] 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.

9.3 COST Action TU0901

The recently concluded programme for European harmonisation of acoustic descriptors [1] has included the determination of Classes for noise from building services, with a range from 20 to 36 dB(A). 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 England.

There is also no qualification of the ventilation condition to be achieved whilst the noise level limits are met. As the Classes are due to become adopted as an ISO Standard, this offers a fantastic opportunity to qualify the ventilation conditions associated with the noise limits.

10. Commissioning

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. Similarly as for insufficient sound insulation between dwellings, excessive ambient noise levels can be harmful to health, and ensuring compliance with the performance requirements that have been established for more than a decade would seem appropriate.

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 buildings would need to be appropriately designed and constructed; perhaps a Robust Details type scheme may also be appropriate. In our experience commissioning measurements are very seldom conditioned by LPAs; without this requirement there is no effective enforcement of the conditions.

Although the noise issues relating to mechanical ventilation have not been extensively researched in the UK, deficiencies in air flow rates are already widespread [39]. The message from the above literature review of over 1000 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.

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 [41]; suppliers of MVHR systems can lack the knowledge and expertise to design appropriate noise control measures even where data is available.

11. Conclusion

Problems with achieving suitable natural ventilation and reasonable internal noise levels have been identified and discussed. The first problem is insufficient qualification of the ventilation condition that should be achieved while meeting the internal ambient noise level limits. It is suggested that as a minimum, the provision of whole dwelling ventilation in accordance with national regulations should be assessed and controlled to meet suitable noise limits, with a requirement for commissioning checks on completion.

The second problem concerns the practical provision of sufficient trickle vents if a natural ventilation strategy is sought; the sensitivity of the façade sound insulation design to the details of the ventilation requirements must be considered early in the design. It is noted that the trickle vent provision may also rely on the design air permeability. The example calculations demonstrate that natural ventilation using System 1 may require so many trickle vents that the achievable performance may be only marginally better than opening windows. Evidence demonstrates that there is often significant under-provision of the necessary quantity of vents in practice; this means that the Building Control body may consider that opening windows provide the required ventilation, while the sound insulation strategy offered to the LPA relies on windows being closed. This problem could be overcome if the combination of ventilation and noise levels – i.e. internal environmental quality – were regulated by a single body. A requirement for commissioning measurements is considered appropriate in all cases.

A common reason for 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. More country-specific research is needed to confirm appropriate upper limits.

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 country-specific research is required to determine suitable noise limit levels for boost ventilation rates from MEV and MVHR. Further country-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 suggested that the minimum requirement for association of noise level limit and ventilation condition is for the whole dwelling ventilation rate required under prevailing national regulations. A requirement for commissioning measurements is considered appropriate in all cases.

Further research is required into acceptable noise levels for the provision of intermittent extract and purge ventilation, from both external sources and mechanical services; owing to the complete lack of data currently, they may be temporarily excluded from consideration within design. The sensitivity to these values is likely to vary between cultures where, for example, people have become accustomed to noise from comfort cooling systems.

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References

[1] COST Action TU0901 - Towards a common framework in building acoustics throughout Europe, B Rasmussen, M Machimbarrena, 2013.

[2] B. Berglund, T. Lindvall, D. Schwela, World Health Organisation Community Noise Guidelines. (2000).

[3] Hurtley C. (ed.), WHO Night Noise Guidelines for Europe. (2009)

[4] S. K. D. Coward, J. W. Llewellyn, G. J. Raw, V. M. Brown D. R. Crump and D. I. Ross Indoor air quality in homes in England. BRE Report 433. Garston, CRC Ltd, (2001).

[5] S. K. D. Coward, J. W. Llewellyn, G. J. Raw, V. M. Brown, D. R. Crump, and D. I. Ross, Indoor air quality in homes in England Volatile organic compounds, BRE Report 446. Garston, CRC Ltd. (2002).

[6] R. Dumont and L. Snodgrass, Volatile Organic Compound Survey and Summarisation of Results: SRC Publication No. I-4800-1-C-92, Saskatchewan Research Council, Saskatoon; cited in Gustavsson J (undated) Air filters and IAQ, undated (1992)

[7] S. G. Howieson, A. Lawson, C. McSharry, G. Morris, E. McKenzie, J.Jackson, Domestic ventilation rates, indoor humidity and dust mite allergens: are our homes causing the asthma pandemic? Building Services Engineering Research and Technology; 24; 137 (2003)

[8] L. Molhave, "Volatile Organic Compounds, Indoor Air Quality and Health" in Indoor Air '90: The fifth International Conference on Indoor Air Quality and Climate, Toronto, Canada, July 29 - August 2, 1990, Vol 5, pp 15-33. (1990) Canada Mortgage and Housing Corporation, Canada; cited in Gustavsson J (undated) Air filters and IAQ, (undated), (accessed 01/01/01)

[9] L. Reinikainen, L. Aunela-Tapola, J. J. K. Jaakkola, Humidification and perceived indoor air quality in the office environment, Occupational and Environmental Medicine; 54:322-327 (1997)

]10] G. Richardson, S. Eick, R. Jones, How is the indoor environment related to asthma?: literature review, Journal of Advanced Nursing, 52(3), 328–339 (2005)

[11] C. G. Bornehag, J. Sundell, L. Hgerhed-Engman, T.Sigsgaard, Association between Ventilation Rates in 390 Swedish Homes and Allergic Symptoms in Children, Indoor Air: Volume 15(4) p 275-280 (2005)

[12] W. Pan, Relationships between air-tightness and its influencing factors of post-2006 new-build dwellings in the UK, Building and Environment, 45 (11) 2387-2399. (2010)

[13] EU Energy Performance of Buildings Directive, EU 2002

[14] Quality of Ventilation systems in Residential Buildings: Status and perspectives in the UK, Alan Gilbert and Chris Knights, BSRIA 2013

[15] S. McKay, D. Ross, I. Mawditt I., S. Kirk, BD 2702 Ventilation and Indoor Air Quality in Part F 2006 Homes, Department for Communities and Local Government. (2010)

[16] Centnerová, L.H., Boerstra, A., Comfort is more than just thermal comfort, Proc. Adapting to Change: New Thinking on Comfort, Network for Comfort and Energy Use in Buildings, London. (2010)

[17] A.M.B. Santos, L.B. Gunnarsen, Optimizing linked pairs of indoor climate parameters. Proceedings of Conference 'Indoor Air 99', Edinburgh, vol.3, 191-197; reported in Centnerová L. H., Boerstra A. (2010) Comfort is more than just thermal comfort, Proceedings of Conference: Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings. (1999)

[18] G. Clausen, L. Carrick, P.O. Fange, S.W. Kim, T. Poulsen, J.H. Rindel, (1993) A comparative study of discomfort caused by indoor air pollution, thermal load and noise. Indoor Air 3, 255–262; reported in Centnerová L. H., Boerstra A., Comfort is more than just thermal comfort, Proceedings of Conference: Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings. (2010)

[19] A Dengel, M Swainson, Overheating in new homes: a review of the evidence, NHBC Foundation Research NF 46, November 2012

[20] BS EN 12354-3, Building Acoustics - Estimation of acoustic performance of buildings from the performance of elements. Part 3: Airborne sound insulation against outdoor sound. (2000)

[21] T. Waters-Fuller, D. Lurcock, NANR116: Open/closed window research: Sound insulation through ventilated domestic windows, Napier University for DEFRA (2007)

[22] Department of the Environment, BRE Digest 338, Insulation against external noise, Buildings Research Establishment. (1988)

[23] F. Nicol, M.Wilson, The effect of street dimensions and traffic density on the noise level and natural ventilation potential in urban canyons, Energy and Buildings 36 423–434, Elsevier (2004)

[24] J. Balvers, R. Bogers, R. Jongeneel, I. van Kamp, A. Boerstra, F. van Dijken, Mechanical ventilation in recently built Dutch homes: technical shortcomings, possibilities for improvement, perceived indoor environment and health effects, Architectural Science Review, 55 (1) 4-14. (2012)

[25] E. Hasselaar, Delft University of Technology, The Netherlands: Why this crisis in residential ventilation? Indoor Air 2008, Copenhagen, Denmark. (2008)

[26] F. Stevenson, I. Carmona-Andreu, M. Hancock, The usability of control interfaces in low-carbon housing, Architectural Science Review, 1–13, (2013)

[27] V. Dorer, D. Breer, EMPA, Swiss Federal Laboratories for Materials Testing and Research: Residential mechanical ventilation systems: performance criteria and evaluations published in Energy and Buildings, 27 (3) 247 – 255. (1998)

[28] P. Op't Veld, C. Passlack-Zwaans, Cauberg-Huygens Consulting Engineers: Evaluation and demonstration of domestic ventilation systems. Assessments on noise, published in Energy and Buildings, 27 (3) 263 – 273. (1998)

[29] D.K. Alexander, H.G. Jenkins, N. Weaver, Occupant Perception of Running Costs of Domestic Mechanical Ventilation Systems, Proceedings 21st AIVC Annual Conference, "Innovations in Ventilation Technology". (26-29 September 2000)

[30] A. Macintosh and K. Steemers, Ventilation strategies for urban housing: lessons from a PoE cases study, Building Research & Information, 33(1), 17–31 (January–February 2005)

[31] P. Concannon, Technical Note AIVC 57 Residential Ventilation, Air Infiltration and Ventilation Centre, International Energy Agency. (2002)

[32] J. Kurnitski, L. Eskola, J. Palonen, O. Seppänen, Use of mechanical ventilation in Finnish houses Helsinki University of Technology, HVAC-Laboratory, Europäisches BlowerDoor-Symposium. (2007)

[33] M. Hady, J. Jan van Ginkel, E. Evert Hasselaar, G. Guus Schrijvers, The relationship between health complaints, the quality of indoor air and housing characteristics. Indoor Air 2008, Copenhagen, Denmark. (2008)

[34] A Dengel, M Swainson, Assessment of MVHR Systems and air quality in zero carbon homes, NHBC Foundation Research NF 52, August 2013

[35] U. Ayr, E. Cirillo, F. Martellotta, Further investigations of a new parameter to assess noise annoyance in air-conditioned buildings, Energy and Buildings 34 (2002) 765–774

[36] Classification of Indoor Environment: Target values, design guidance and product requirements, LVI 05-10440, Finnish Society of Indoor Air Quality and Climate, Helsinki. (2008)

[37] Passivhaus Institut, Requirements and testing procedures for energetic and acoustical assessment of Passive House ventilation systems for certification as "Passive House suitable component", (2009)

[38] BS EN 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (2007)

[39] BSRIA, Domestic ventilation systems: a guide to measuring airflow rates, Exposure draft for industry comments ED46/ 2013. (2013)

[40] Quality of Ventilation systems in Residential Buildings: Status and perspectives in the UK, Alan Gilbert and Chris Knights, BSRIA 2013

[41] BS EN 13141-7, Ventilation for buildings - Performance testing of components / products for residential ventilation - Part 7. Performance testing of a mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for single family dwellings. (2004)