Noise from ventilation systems in dwellings – Regulations and field test procedures in selected countries in Europe

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ABSTRACT

In most countries in Europe, regulatory noise limits apply for service equipment in housing. During the last few decades, mechanical ventilation with heat recovery (MVHR) has become increasingly prevalent in new and retrofitted housing in Europe. The MVHR systems supply fresh air to obtain good indoor air quality, with minimal heat losses. However, the systems may operate continuously 24 hours/day and transmit noise into and between rooms by many possible paths. In practice, many people get annoyed or disturbed by the noise, especially during nighttime or when having quiet activities. Some countries have stricter service equipment noise limits for continuous sources, and stricter limits also apply for upper quality classes in acoustic classification schemes. Thus, both design and measurements become challenging.

The aim of this paper is to investigate the noise limit values and descriptors applied to ventilation systems in housing in selected countries in Europe and to compare and discuss the field test procedures typically applied.

1. INTRODUCTION

Energy efficiency requirements in Europe have been the force of the widespread of mechanical ventilation with heat recovery (MVHR) in new and retrofitted housing. For buildings with an airtight building envelope, MVHR enables a good control of heat losses, while controlling air quality, and that's why such ventilation systems have become prevalent nowadays in many European countries.

MVHR reduces transmission of outdoor noise as well, because there are no direct external intake vents. The systems are usually composed of an internal unit, which has two fans and a heat recovery exchanger. Fresh air is preheated in the heat recovery exchanger, and it is supplied to bedrooms and living rooms though ducts, while exhaust air is extracted from kitchens and bathrooms. Noise produced by the internal unit can be transmitted though the ductwork and grilles to the habitable rooms and can therefore be a cause of noise annoyance and dissatisfaction, especially in bedrooms at nighttime.

Figure 1 shows a common layout of a MVHR in a dwelling. The colours of the ductwork correspond to the type of airflow circulating: Blue for air intake and supply air to rooms; orange for return

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and exhaust air. Arrows indicate the movement of air. The prevalent sound transmission path associated with MVHR is duct-borne noise through supply air ducts from the heat recovery unit and radiated through the grilles in habitable rooms, including living rooms and bedrooms. A definition of habitable rooms is found in [1], Clause 3.1.10.

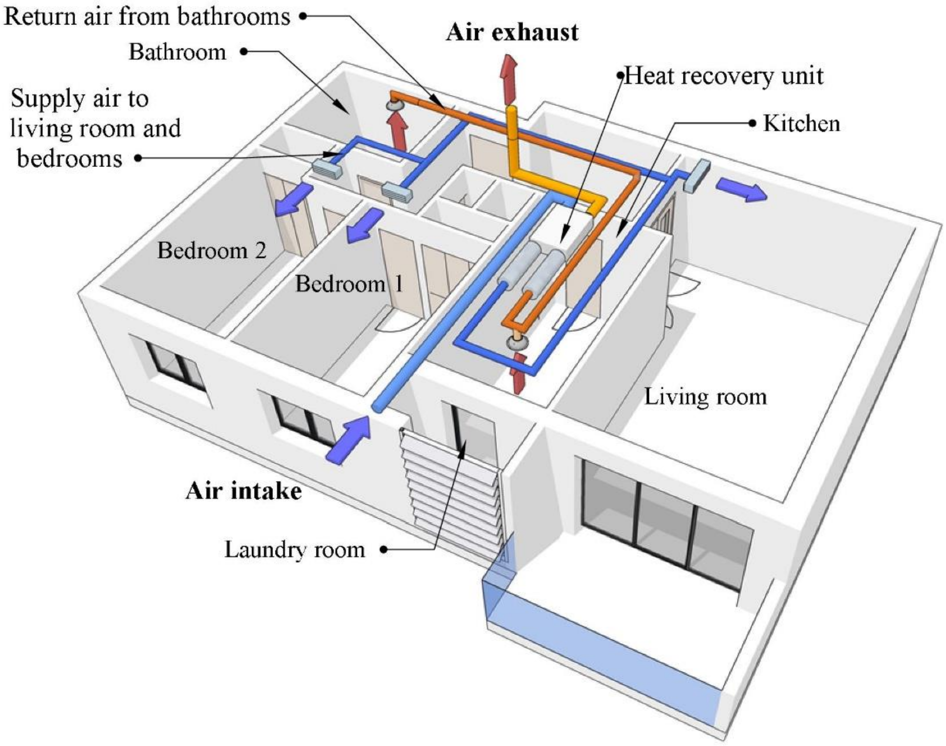

Figure 1 – Typical layout of a MVHR system in a dwelling

Provisions in each country establish minimum ventilation rates. MVHR systems will work continuously 24 hours a day. Depending on the equipment, heat recovery units will adjust the airflow automatically or manually. In general, airflow controls can be based on CO_2 detectors, humidity detectors or manual controls, which occupants can activate manually to set the airflow to different points to meet the ventilation necessities of the dwelling. Several studies revealed, cf. e.g. [2], that many occupants will turn off the ventilation equipment or “hack” it, if they find the noise from the system annoying, e.g. due to sleep disturbances or when they want silence due to quiet activities. In the end this implies a deterioration of air quality and health as well – or damage of the system.

The purpose of this paper is to compile and compare the acoustic requirements for service equipment noise, especially for ventilation systems, in several European countries, aiming at improving national procedures and international standards. Various test methods, test procedures and test conditions are applied in various countries, see the following sections.

2. SERVICE EQUIPMENT NOISE IN ACOUSTIC REGULATIONS AND GUIDELINES

In most countries in Europe, acoustic regulations now exist for housing and in several countries also for other building categories like e.g. schools, kindergarten, hospitals and office buildings. In addition, and/or as an alternative, some countries also have guidelines or acoustic classification schemes. Acoustic regulations and classification criteria are typically about: Airborne sound insulation between rooms; Impact sound insulation between rooms; Facade sound insulation; Service equipment noise; Reverberation time or sound absorption. – Building acoustic criteria are specified by a descriptor, a limit value, reference to a standard and sometimes to specific conditions e.g. frequency range and/or test conditions. In Europe, most countries refer to ISO field measurement and rating standards, typically [3], [4] [5], [6], [7], [8], [9], [10] for the above-mentioned acoustic performance areas.

This paper deals with noise from ventilation systems, being a part of service equipment. Several examples of service equipment are mentioned in e.g. [1], Clause 3.1.6. The current paper is related to service equipment noise and more specifically to limits for ventilation noise. The ISO test methods applied are typically ISO 10052 [5] or ISO 16032 [6] – being a survey and a more detailed engineering method, respectively – but some countries do not refer directly to any of these methods, some refer to both as options, and some have national procedures. In many countries, it is required or indicated that corrections are to be made for tones, impulses, low frequencies etc., but often clearly defined methods are either not referred to or in separate documents.

The two test methods are similar with the same denotations for single-number quantities and three measurements of sound level (one in a corner and two in the reverberant field), but ISO 10052 is a survey method and thus simpler, and no background correction is applied (which is a main complaint by many consultants doing such tests). Measurements can be normalized to reverberation time with both standards, and ISO 3382-2 [7] is used in both cases, but ISO 10052 allows use of tabulated reverberation index data included in the standard.

3. CHOOSING COUNTRIES AND METHODOLOGY FOR THE COMPARATIVE STUDY

When choosing countries for the study, it was decided to get various geographical parts of Europe presented, taking into account also the authors' language skills. The countries selected are the same as those chosen for a study on acoustic regulations for hospitals [11]. Only countries with published regulations or guidelines are included, thus omitting drafts. In Table 1, the countries are listed in alphabetical order. For Italy, we have split up into public and private dwellings, since regulations became different after the publication of the 2017 decree [17].

Table 1 – Acoustic regulations for HOUSING – Overview countries selected for a comparative study in Europe.

Acoustic regulations for HOUSING – Overview countries selected for a comparative study in Europe – April 2022				
Country	**BR**	**ACS**	**ACS quality classes***	**Comments on acoustic classes and relation to building regulations**
Denmark	[12]	[22]	A, B, C, D, E, F	BR [1] refers to in ACS [22], Class C, as mandatory minimum performance.
England	[13], [14]	N/A	N/A	
France	[15]	N/A	N/A	
Italy (public)	[16], [17]	[23]	I, II, III, IV	For public dwellings(*), [17] refers to ACS, Class II is the minimum mandatory performance. (*)[17] applies to dwellings owned by public authorities.
Italy (private)	[16]	[23]	I, II, III, IV	For private housing, limit values are found in [16]. The Acoustic Classification Scheme [23] is voluntary
Norway	[18]	[24]	A, B, C, D	BR [18] refer to ACS [24], Class C, as mandatory minimum performance.
Portugal	[19]	N/A	N/A	
Spain	[20]	[25]	A, B, C, D, E, F	Classification according to [25] is voluntary. No reference in BR [20].to [25].
Turkey	[21]	[21]	A, B, C, D, E, F	BR [21] refer to ACS [21], Class C, as mandatory minimum performance.
BR = Building Regulations (regulatory requirements); ACS = Acoustic Classification Scheme; * Upper class first. Note: Even in case of the same class denotation, descriptors and limit values vary between countries.				

The methodology for collection of data for national acoustic regulations follows the principles outlined in [26] and [27], i.e. the analysis is primarily based on direct access to the documents describing the requirements. Such documents could be building regulations or publications referred to in the building regulations. In some cases, typically for countries with "difficult" languages or unclear requirements, interpretation was discussed with national experts. As indicated in [28], structures of legislation differ widely, including contents, size and number of relevant documents. In some countries, the documents specifying the requirements or recommendations are available at the web, but in other countries, they must be purchased from the standardization organizations. The work builds on experience and contacts from previous surveys. The major challenges were finding the right documents and sections, and to make the technical interpretations.

From Table 1, it appears that three of the selected countries (DK, NO, TR) refer to Class C in the national acoustic classification scheme as the acoustic regulations. This way makes it reasonably easy to get an overview of the acoustic requirements for housing, since all limit values – including those presented in Table 2 – are found in Class C in the classification documents [22], [24] and [21], respectively. In general, regulations are mandatory and acoustic classification voluntary, unless referred to in the regulations.

Examples of acoustic class limits A-F according to DS 490 [22] are indicated below for service equipment noise in habitable rooms. Classes A-F are shown in descending order:

Class	A	B	C	D	E	F
$L_{A,eq}$	≤ 20 dB	≤ 25 dB	≤ 30 dB	≤ 35 dB	≤ 40 dB	None

The Danish building regulations [12] refer to Class C in [22] for information about the mandatory minimum performance. Classes D, E, F have lower performance than required for new-build, and classes A-B higher performance than regulations, i.e. better comfort and protection against noise.

4. LIMIT VALUES FOR SERVICE EQUIPMENT NOISE

Limit values for service equipment noise are found in Table 2. References to measurement methods are found in the building regulations or in the guidelines referred to in the regulations or in the national guidelines.

The ISO standards referred to for ventilation noise are typically ISO 10052 [5] or ISO 16032 [6] or both, but in several countries additional methods apply for low-frequency noise and correction for pure tones, impulses and intermittent noise. Some countries apply different limits and procedures for continuous sources, e.g. ventilation systems, and other sources with changing noise emission during the operating cycle.

Table 2 – Acoustic regulations for HOUSING – Service equipment noise limits for dwellings (habitable rooms).

Acoustic regulations for HOUSING (1) – Service equipment noise – April 2022					
Country	**BR**	**Test method**	**Requirement (2) [dB]**	**Furnished**	**Comments**
Denmark	[12]	ISO 10052 and DK guideline [29]	$L_{A,eq} \leq 30$	–	If measured in a furnished room, +3 dB is added to the measured value. BR [12] refers to Class C in ACS [22] as the requirement for habitable rooms.
England	[13], [14]	National procedure and Guideline [31]	($L_{Aeq,T} \leq 30$) ($L_{Aeq,T} \leq 45$)	Not specified	Levels for living rooms and bedrooms, for ventilation systems. Levels for kitchens and bathrooms. Limits are recommendations just for ventilation noise.
France	[15]	ISO 10052 and FR guideline [32]	$L_{nAT} \leq 35$ $L_{nAT} \leq 30$ $L_{nAT} \leq 30$ $L_{nAT} \leq 30$	Not specified	Noise produced by individual heating or cooling systems. Noise produced by mechanical ventilation systems. Noise produced by other equipment belonging to another dwelling. Noise produced by collective building equipment, such as lifts, water pumps, boilers, etc. $L_{nAT} = L_{ASmax,nT}$. standardized to the reference reverberation time (average of the RT values for 500 Hz, 1000 Hz et 2000 Hz). Note: Noise limits for living rooms and bedrooms. Limit for kitchens specified in [15].
Italy (public)	[16], [17]	ISO 10052 or ISO 16032 and national procedure [17]	$L_{ic} \leq 28$ $L_{id} \leq 33$	+	Equivalent SPL from service equipment with continuous operation. Maximum SPL from service equipment with discontinuous operation. Note: The descriptors are explained in [23].
Italy (private)	[16]	ISO 10052 or ISO 16032	$L_{Aeq} \leq 25$ $L_{ASmax} \leq 35$	Not specified	Equivalent SPL from service equipment with continuous operation. Maximum SPL from service equipment with discontinuous operation.
Norway	[18]	ISO 16032	$L_{p,A,T} \leq 30$ $L_{p,AF,max} \leq 32$	+	BR [18] refers to Class C in ACS [24]. 5 dB higher sound levels are ok in kitchens, WC, bathrooms, entrances etc. In addition to the limits indicated, there are also LF-limits for octaves 31,5-125 Hz.
Portugal	[19], [33]	National procedure [33]	$L_{Ar,nT} \leq 27$ $L_{Ar,nT} \leq 32$ $L_{Ar,nT} \leq 40$	Not specified	For building services producing a continuous noise. For building services that works intermittently For an emergency power unit. $L_{Ar,nT} = L_{A,eq}$ + corrections for background noise, tonal noise..
Spain	[20], [34]	National procedure [34]	$L_{k,n} \leq 25$ $L_{k,n} \leq 30$	Not specified	For bedrooms in dwellings. Limits for the night period, 23:00 – 7:00h. For the day and evening periods, limits are: $L_{k,d}$; $L_{k,e} \leq 35$ For living rooms in dwellings. Limits for the night period, 23:00 – 7:00h. For the day and evening periods, limits are: $L_{k,d}$; $L_{k,e} \leq 40$ Limit value $L_k = L_{A,eq,T}$ + corrections for background noise, tonal, impulsive and LF noise
Turkey	[21]	ISO 10052 or ISO 16032	$L_{A,eq,nT} \leq 30$ $L_{A,eq,nT} \leq 35$	+	Limit for continuous noise in bedrooms during night-time, 23:00 – 07:00. Limit for continuous noise in living areas, kitchen - during 24 hours.
			$L_{AF,max,nT} \leq 34$		Limit for intermittent noise.
(1) Overview information only. Detailed criteria and conditions are found in references. (2) Limits in (brackets) = Recommendation.					

From Table 2, it is seen that different descriptors are applied, which make comparisons more complicated. In general, all countries, except France, rely on a descriptor based on L_{Aeq}, A-weighted equivalent sound pressure level for mechanical ventilation systems. In France, $L_{A,Smax}$ applies to all building services including ventilation noise. Italy and Turkey apply different descriptors depending on, whether the noise is continuous, which is the case for ventilation noise, or intermittent, see Table 2. Some details about each of the eight countries included in Table 2 are found below.

Denmark

In DK, the building code guideline [12] refers to ISO 10052 [5] for measurement of service equipment noise, but for ventilation noise (noise source in the room, where the measurement is made) is prescribed measurement in just one microphone position for each source, cf. [29]. The microphone is placed as indicated in Figure 2, implying that that the noise level from the ventilation system is dominant and less influenced by the higher levels in the middle of the room.

However, the Danish classification standard [22] for dwellings has six classes A-F with limits starting with 20 dB (class A) and higher. Since many people are disturbed by ventilation noise during sleep and quiet activities, even if the building code requirement 30 dB is fulfilled, it has been considered to make the ventilation noise limit 5 dB stricter to get quieter living rooms and bedrooms and thus create a healthier indoor climate.

As a starting point, a voluntary sustainability class for ventilation noise in dwellings has been introduced in [35] with a limit 25 dB, i.e. 5 dB stricter than regulations. The purpose is to test the feasibility of implementing and measuring such 5 dB quieter ventilation systems and then later decide to make the limit mandatory, if practice supports such step.

Since correction for background noise is not included in the ISO 10052 procedure, it is often difficult or impossible to measure low levels of ventilation noise, even if the microphone position is quite close to the source and does not include higher noise levels more far away from the source. In DK, it is considered either to switch to ISO 16032 [6] (allowing background noise correction) or update the national guideline [29], so correction for background noise can be made. However, it would be more optimal to revise the ISO standards aiming at optimizing the procedure for ventilation noise measurements, including also microphone positions for such tests.

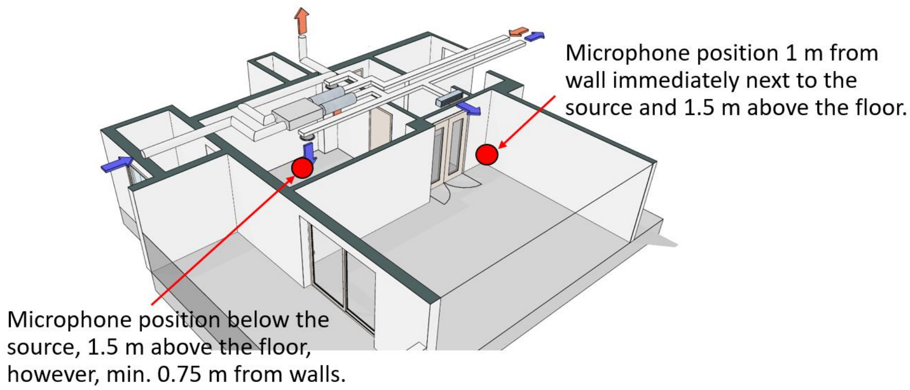

Figure 2 – Microphone positions for measurement of ventilation noise according to the national guideline [29] in DK.

England

In England, there are not requirements for the sound pressure levels produced by service equipment noise in Building Regulations [14]. They refer to guidance document BS 8233 [30], which specifies internal ambient noise levels corresponding to the sum of all sound sources: external and internal and is requested from local authorities in several parts across England.

In addition, Approved document F, Ventilation [14], of the Building regulations includes recommendations for the sound pressure levels for ventilation noise included in Table 2, and specifies a measurement time of 1 minute, if the source is steady. This document refers to BS 8233 [30], which also refers to ANC guidelines [31]. For ventilation noise, NR criteria are also given in BS 8233 [30].

France

Requirements for building services vary depending on the type of equipment (individual heating, ventilation, etc.). In the case of ventilation systems, Table 2 includes limit values for living rooms and bedrooms. Limit values for kitchens are 5 dB higher.

The descriptor used is $L_{\mathrm{nA}T}$ which corresponds to $L_{\mathrm{ASmax,n}T}$ standardized to the reference reverberation time, which is the average of 500, 1000 and 2000Hz measured according to ISO 3382-2. Measurement procedures in France are based on ISO 10052 [5], but France has published a guideline [32] on acoustic measurements in buildings. In the case of ventilation systems, they specify the test conditions for the equipment and the airflow rates.

Italy

In Italy, acoustic requirements apply to all buildings [16]. In addition, Decree [17] applies to public buildings, including social housing, and requires a minimum class II [23] for public housing, that is the reason why there are two rows for table 2 for Italy.

In both regulations, the approach is to use a $L_{\mathrm{AS,max}}$ for intermittent sounds, and L_{Aeq} for continuous sounds, such as ventilation systems. ISO 10052 [5] and ISO 16032 [6] are referred to for measurements.

Norway

In Norway, the building code [18] refers to NS 8175 [24], Class C. The measurement method is ISO 16032 [6].

Portugal

In Portugal, limits for sound pressure levels produced by building services only apply to collective equipment, such as lifts, centralized ventilation systems, collective boilers, etc. So individual ventilation systems like MVHR, where each home has its own unit supplying fresh air to the dwelling, have to meet [33], which applies to noise emitted from neighbouring activities, and does not apply to the indoor sound pressure levels produced by own equipment.

The descriptor for service equipment noise used in regulations is $L_{\mathrm{Ar,n}T}$, which is L_{Aeq} standardized to reverberation time and corrected by reverberation time and tonal noise following the procedure of [33].

Portuguese regulations do not specify any ISO or CEN standard. They literally say that measurements must be made according to Portuguese standards, and if not, to any European or international standard, which would typically be ISO 10052 [5] or ISO 16032 [6]. The assessment must be made according to Reglamento General do Ruido [33].

Spain

The Spanish Building Code [20] refers to Spanish Decree RD 1367/2007 [34] being an environmental law transposed from [36], which applies to all environmental noise sources and contains the requirements for sound pressure levels in dwellings due to building service equipment, including ventilation systems. Requirements vary depending on the period: day, evening and night. The descriptor, $L_{\mathrm{Keq},T}$, is $L_{\mathrm{Aeq},T}$, measured from 20 to 20,000 Hz and corrected for background noise, emerging tones, low-frequency noise and impulsive components. This decree also specifies the measurement and assessment procedures which are different from ISO 16032 [6] and ISO 10052 [5]. Measurements are not standardized to reverberation time, and no indication is given, if rooms are empty or furnished.

In September 2021, an acoustic classification system was published in Spain [25]. Requirements for service equipment noise are similar to those of ISO/TS 19488 [1].

Turkey

Both standards ISO 10052 [5] and ISO 16032 [6] are applicable according to regulations [21].

5. SUMMARY, DISCUSSION & CONCLUSIONS

The need for energy efficient housing has led to the use of MVHR systems in dwellings across Europe. Adequate airflows are supplied through ductwork to rooms and extract from toilet rooms and kitchens by means of a heat recovery unit which works continuously, 24 hours a day at different speeds providing the right airflow. Thus, noise produced by the internal unit can be transmitted through ductwork to noise sensitive rooms such as living rooms and bedrooms.

Before the spread of MVHR systems, fresh air was supplied to dwellings by vents and opening windows, so ventilation noise was part of outdoor noise. Extract fans were usually located in kitchens and bathrooms, which are less noise sensitive rooms. But in MVHR, grilles are placed in living rooms and bedrooms, and may be a source of noise annoyance, if attention has not been paid in the planning, design and construction of MVHR. This is a key issue, as studies have shown that whenever ventilation systems are perceived as noisy, occupants may try turning them off, resulting in an inadequate air flow rate and a health risk [2] and maybe even damage of the ventilation systems. Another weakness of many MVHR systems is the poor sound insulation between rooms internally in dwellings, if damping of the ducts is missing – leading to lack of privacy, annoyance and complaints.

This paper includes a comparison of the requirements in eight selected European countries for indoor service equipment noise levels, focusing on ventilation noise. In most countries, requirements apply to building service equipment in general. Only England and France have requirements specifically for ventilation systems, but most countries make a difference between continuous sound sources (like e.g. ventilation systems) and intermittent sources like lifts, plumbing, etc.

The limits in Table 2 in this paper show that most countries have different descriptors (metrics). Although there are two ISO standards for service equipment noise measurements, ISO 10052 [5] and ISO 16032 [6], some countries have their own measurement procedures like Spain and England. France has a very comprehensive guideline [32] concerning measurement procedures, including ISO 10052. In addition, several countries apply corrections for tonal noise, impulsive noise and low frequency noise, cf. the national guidelines referred to in Table 2. These guidelines could also define other conditions for the measurement, for example if limit applies to furnished or unfurnished rooms. The Danish test procedure [29] define microphone positions different from those in the ISO standards.

Letting aside differences in descriptors and measurement procedures, the descriptors are based on L_{Aeq}, and the requirements are typically around 30 dB in living rooms and bedrooms.

In some countries, the limit value for ventilation noise seems to be too weak and should be made stricter, thus ensuring better protection from ventilation noise disturbances. In [2], it is recommended to carry out laboratory studies with subjective testing and optimization of mechanical ventilation noise characteristics for sleep, and for relaxation, using measured source data. Such research could help determine the annoyance caused by MVHR systems and to optimize limits.

The comparison between countries indicates that it would be useful to collect experiences with national test procedures, not least for measurements of low noise levels. Many ventilation systems operate automatically, and to get reliable and reproducible test results, it is of crucial since that the adjustment of the system is carried out before the test and described in the test report and that the operating conditions for the test are well-defined and described as well. Thus, both ISO 10052 [5] and ISO 16032 [6] should be revised. Actually, a revision of ISO 16032 has just started (early 2022), and it seems obvious to make sure that the procedure for ventilation noise is evaluated carefully, including consideration of microphone positions and contents of test report, which should provide more information about the test, e.g. temperature, humidity, date and results of the system adjustment and preferably airflow rate. It would be useful to have a form for expression of ventilation noise results included in the revised ISO 16032 – similar principle as for airborne and impact sound insulation test results in informative Annexes in ISO 10052 and ISO 16283.

Finally, it would be useful with increased enforcement of regulations, including check of field test reports, since enforcement in the past used to improve compliance with regulations and to create more awareness about the performance. A natural part of increased check of system performance would be a sort of certification of those performing the field tests of noise from ventilation systems.

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7. REFERENCES

[1] ISO/TS 19488:2021. Acoustics — Acoustic classification of dwellings.

[2] Jack Harvie-Clark, Nick Conlan, Weigang Wei & Mark Siddall (2019): *How loud is too loud? noise from domestic mechanical ventilation systems*. International Journal of Ventilation, 18(3):1-10. https://doi.org/10.1080/14733315.2019.1615217

[3] ISO 16283, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 1: Field measurements of airborne sound insulation between rooms, 2014. – Part 2: Field measurements of impact sound insulation of building elements, 2020. – Part 3: Field measurements of airborne sound insulation of facade elements and facades, 2016.

[4] ISO 717:2020, Acoustics – Rating of sound insulation in buildings and of buildings elements. – Part 1: Airborne sound insulation. – Part 2: Impact sound insulation.

[5] ISO 10052:2021, Acoustics – Field measurements of airborne and impact sound insulation and of service equipment sound – Survey method. Note: Under revision.

[6] ISO 16032:2004, Acoustics – Measurement of sound pressure level from service equipment in buildings – Engineering method.

[7] ISO 3382-2: 2008, Acoustics – Measurement of room acoustic parameters – Reverberation time in ordinary rooms.

[8] ISO 1996-1:2016 Acoustics – Description, measurement and assessment of environmental noise -- Part 1: Basic quantities and assessment procedures

[9] ISO 1996-2:2017 Acoustics – Description, measurement and assessment of environmental noise -- Part 2: Determination of sound pressure levels.

[10] ISO/PAS 20065:2016. Acoustics — Objective method for assessing the audibility of tones in noise — Engineering method.

[11] Rasmussen, B., Carrascal García, T., & Secchi, S. (2021). *Acoustic regulations for hospital bedrooms – Comparison between selected countries in Europe*. In T. Dare, S. Bolton, P. Davies, Y. Xue, & G. Ebbitt (Eds.), Proceedings of Inter-Noise 2021 (pp. 2793-2800). Noise-Con Proceedings Vol. 21 https://doi.org/10.3397/IN-2021-2230

[12] *Bygningsreglement 2018* (Building regulations 2018). Danish Transport, Construction and Housing Authority, 2017. Copenhagen, Denmark. http://bygningsreglementet.dk (with link to English version). Note: BR2018 refers to *BR2018 Vejledning om lydforhold* (BR2018 Guideline for acoustic conditions). http://bygningsreglementet.dk/Tekniske-bestemmelser/17/Vejledninger.

[13] Ministry of Housing, Communities & Local Government (2015). Building regulation in England. Resistance to sound: Approved Document E. London, England. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/468870/ADE_LOCKED.pdf

[14] Ministry of Housing, Communities & Local Government (2015). Building regulation in England. Ventilation: Approved Document F. Volume 1. Dwellings. London, England. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1045918/ADF1.pdf

[15] CNB (2017). *Guide du CNB. nº 6. Réglementations acoustiques des bâtiments. (Acoustic building regulations)*. Conseil National du Bruit (French Noise Council). Note: Includes a guide to French acoustic regulations. http://www.bruit.fr/images/stories/pdf/guide-cnb-6-reglementations-acoustiques-batiments-novembre%202017.pdf.

[16] Decreto 5 dicembre 1997, *Requisiti acustici passivi degli edifici (Determination of passive acoustic requirements for buildings)*, 1997 (in Italian). http://www.gazzettaufficiale.it/eli/id/1997/12/22/97A10190/sg

[17] Decreto 11 ottobre 2017, Adozione dei criteri ambientali minimi per gli arredi per interni, per l'edilizia e per i prodotti tessili (Adoption of minimum environmental criteria for interior furnishings, construction and textile products) (in Italian). Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Italy, 2017. http://www.gazzettaufficiale.it/eli/id/2017/01/28/17A00506/sg..

[18] DIBK (2017). *Byggteknisk Forskrift (TEK17). Veiledning om tekniske krav til byggverk.* (Regulations on technical requirements for building works). Direktoratet for byggkvalitet, Oslo. (Norwegian Building Authority). https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/
Note: NS 8175:2019 has been applied, although the latest TEK17 (April 2020) refers to Class C in NS 8175:2012 concerning acoustic requirements. (https://dibk.no/globalassets/byggeregler/regulation-on-technical-requirements-for-construction-works--technical-regulations.pdf)

[19] Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, *Decreto-Lei 96/2008. Regulamento dos Requisitos Acústicos dos Edifícios (RRAE) (Portuguese Building Acoustics Code)*. 2008, pp. 3359–3372. http://data.dre.pt/eli/dec-lei/96/2008/06/09/p/dre/pt/html

[20] Spain, Ministry of infrastructure, *Documento Básico DB HR Protección frente al Ruido. Código Técnico de la Edificación. (DB HR Protection against noise. Spanish Building Code)*. 2009. https://www.codigotecnico.org/images/stories/pdf/proteccionRuido/DBHR.pdf.

[21] Turkish Ministry of Environment and Urbanization (2017). *Binalarin Gürültüye Karşi Korunmasi Hakkinda Yönetmelik* (Regulation on Protection of Buildings against Noise). Republic of Turkey Official Gazette. www.resmigazete.gov.tr/eskiler/2017/05/20170531-7.htm. Note: For more information, see: Ayca Sentop, Nurgun Tamer Bayazit, Selma Kurra, Dilara Demir (2017). *A case study for implementation of the classification scheme i in the new sound insulation regulation in Turkey*. InterNoise2017, Hong Kong.

[22] DS 490:2018, *Lydklassifikation af boliger* (Sound classification of dwellings). Danish Standards, Denmark.

[23] UNI 11367:2010 *Acustica in edilizia – Classificazione acustica delle unità immobiliari – Procedura di valutazione e verifica in opera* (Building Acoustics - Acoustic classification of building units - Evaluation procedure and in-situ measurements). UNI, Italy.

[24] NS 8175:2019, *Lydforhold i bygninger - Lydklasser for ulike bygningstyper* (Acoustic conditions in buildings - Sound classification of various types of buildings), Standards Norway. Note: English version published March 2020.

[25] UNE 74201:2021. Acústica. Esquema de clasificación acústica de edificios. (Acoustics - Acoustic classification scheme for buildings). UNE. Spain

[26] Rasmussen, B. (2010). *Sound insulation between dwellings - Requirements in building regulations in Europe*. Applied Acoustics. 71(4):373-385. Available from: 10.1016/j.apacoust.2009.08.011

[27] Rasmussen B. (2019) *Sound insulation between dwellings – Comparison of national requirements in Europe and interaction with acoustic classification schemes*. Proceedings of ICA 2019, 23rd International Congress on Acoustics, Sept. 2019, Aachen, Germany. Deutsche Gesellschaft für Akustik (DEGA e.V.). https://doi.org/10.18154/RWTH-CONV-239983

[28] Rasmussen, B. (2018). *Building acoustic regulations in Europe – Brief history and actual situation*. Baltic-Nordic Acoustics Meeting 2018, Reykjavik. Nordic Acoustics Association, Proceedings, Vol. 2018.

[29] Rasmussen, B., Hoffmeyer, D., & Olesen, H. S. (2017). *Udførelse af bygningsakustiske målinger (Performing building acoustic field measurements)*. SBi-guideline No. 217, 2017 (2.ed.), SBi Forlag.

[30] BS 8233:2014. *Guidance on sound insulation and noise reduction for buildings.*

[31] ANC (2020). Measurement of sound levels in buildings. Version 1.0. https://www.association-of-noise-consultants.co.uk/measurement-of-sound-levels-in-buildings/

[32] Ministêre de l'Ecologie, du Developpement durable et de l'Energie. Ministêre du Logement et de l'Égalité des Territoires 2014. *Guide de Mesures Acoustiques (Acoustic Measurement Guide)*. Paris, France. https://www.ecologie.gouv.fr/sites/default/files/dgaln_guide_mesures_acoustiques_aout_2014.pdf

[33] Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, *Decreto-Lei n.º 9/2007. Regulamento geral do ruído*, (Portuguese Noise Pollution Act) Diário da República n. 12/2007, Série I. 2007, pp. 389–398. http://data.dre.pt/eli/dec-lei/9/2007/01/17/p/dre/pt/html

[34] Ministerio de la Presidencia, RD 1367/2007de 19 de octubre, por el que se desarrolla la Ley 37/2003, de 17 de noviembre, del Ruido, en lo referente a zonificación acústica, objetivos de calidad y emisiones acústicas. (RD 1367, which develops Law 37/2003, in terms of acoustic zoning, quality objectives and acoustic emissions). BOE 23/10/2007. Vol. 254. 2007, pp. 42952-42973. Madrid, Spain.

[35] Danish National Agency for Housing and Planning (2020). *Vejledning om den frivillige bæredygtighedsklasse (Guideline about the voluntary sustainability class)*. https://baeredygtighedsklasse.dk/ (online) or pdf: https://baeredygtighedsklasse.dk/-/media/TBST-DA/Byggeri/Lister/Publikationer/Vejledning-om-den-frivillige-baeredygtighedsklasse-maj-2020.pdf. More information about the voluntary sustainability class prepared by Danish Transport, Construction and Housing Authority (under the Danish Ministry of the Interior and Housing). https://bygst.dk/byggeri/den-frivillige-baeredygtighedsklasse/

[36] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise -, vol. DIRECTIVE. 2002, p. de L 189/12 a L 189/25. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN