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Field tests of low noise levels from MVHR ventilation systems – Overview obstacles and pilot test of test procedure improvement

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The Danish building regulations specify $L_{Aeq} \leq 30$ dB for ventilation noise in dwellings, both for new-build and new systems in renovated housing. The test method referred to is based on the survey method ISO 10052. In practice, many people get annoyed or disturbed by ventilation noise during night or when having quiet activities. Several people complain about the noise, and some people change the operation of the MVHR system or even destroy it. Due to dissatisfaction from occupants, it is considered reducing the regulatory limit to $L_{Aeq} \leq 25$ dB in living and sleeping rooms, which is currently being tested in a voluntary sustainability class (in Danish abbreviated FBK), including use of the engineering method ISO 16032 for background noise correction as prescribed in the FBK guidelines.
However, even with a background noise correction specified, for both limits $L_{Aeq} \leq 30$ dB and $L_{Aeq} \leq 25$ dB, it's often a challenge to quantify the background noise from various activities or traffic noise in the rooms to be tested. For that main reason, amended test procedures compensating for the shortcomings of the basic test procedures are needed. One potential tool might be increasing temporarily the airflow during test, implying much higher noise levels and thus less sensitivity to background noise, and then subsequently adjust the noise level to fit the nominal air flow, before reporting.
The paper describes test results from a preliminary field test with increased air flow, summarizes conclusions and indicates suggestions for a wider, future field study.

1 Introduction

During the latest decade, sustainability has got an increased focus and high ranking at the national agenda in most countries in Europe. In Denmark, the National Strategy for Sustainable Construction was published in 2021 [1], and one of the tools was a voluntary sustainability class, abbreviated FBK, published in 2020 [2]. FBK has nine topics, one of them being FBK8 about ventilation noise in living and sleeping rooms in dwellings. The reasons for including FBK8 was an increased focus on energy savings combined with a higher awareness on indoor air quality, and that MVHR ventilation systems have been installed in a high number of dwellings, but unfortunately with many complaints about ventilation noise.

The Danish building regulations are found in [3] with acoustic requirements in Ch. 17 and acoustic limit values in the related guideline [4]. For ventilation noise, the current limit is $L_{Aeq} \leq 30$ dB in dwellings, and the FBK8 limit is $L_{Aeq} \leq 25$ dB.

This paper focuses on field measurement of ventilation noise and especially on test of low noise levels.
The paper can be considered as a follow-up of conference papers from InterNoise2022 [5] and FA2023 [6].

2 Ventilation noise limits and test methods in building codes

Service equipment noise limits have existed for decades in building codes in many European countries. An overview of current limits for selected countries in Europe is found in Section 2.1. Service equipment consists of many different sources, e.g. heating, water supply, waste water, toilets, lifts and ventilation systems. Since this paper is initiated due to discussions in Denmark about field tests of ventilation noise, especially for cases with limits below regulation, Section 2.2 specifies details about ventilation noise limits in Denmark according to Building Regulations and to FBK8.

2.1 Ventilation noise limits in selected countries in Europe

Limit values for service equipment noise in selected countries in Europe are found in Table 1. References to measurement methods are found in the building regulations or in the guidelines referred to in the regulations or in other national guidelines. The ISO standards referred to for ventilation noise are typically ISO 10052 [7] and/or ISO 16032 [8], [9]. 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. For reverberation time measurements, the method [10] might be used or, if ISO 10052 [7] is applied, according to the tables in [7]. It should be noted that the ISO standards are implemented as EN standards and subsequently as national standards in CEN member countries.

Table 1: Overview service equipment noise limits for dwellings (habitable rooms) in selected countries in Europe. Table copied from InterNoise2022 paper [5], Table 2. Note: Reference numbers in the table refer to the list of references in [5].

Acoustic regulations for HOUSING (1) – Service equipment noise – April 2022					
Country	**BR**	**Test method**	**Require-ment (2) [dB]**	**Fur-nished**	**Comments**
Denmark	[12]	ISO 10052 and DK guideline [29]	$L_{A,eq} \le 30$	–	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]	($L_{Aeq,T} \le 30$) ($L_{Aeq,T} \le 45$)	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]	$L_{nAT} \le 35$ $L_{nAT} \le 30$ $L_{nAT} \le 30$ $L_{nAT} \le 30$	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]	$L_{ic} \le 28$ $L_{id} \le 33$	+	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	$L_{Aeq} \le 25$ $L_{ASmax} \le 35$	Not specified	Equivalent SPL from service equipment with continuous operation. Maximum SPL from service equipment with discontinuous operation.
Norway	[18]	ISO 16032	$L_{p,A,T} \le 30$ $L_{p,AF,max} \le 32$	+	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]	$L_{Ar,nT} \le 27$ $L_{Ar,nT} \le 32$ $L_{Ar,nT} \le 40$	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]	$L_{k,n} \le 25$ $L_{k,n} \le 30$	Not specified	For bedrooms in dwellings. Limits for the night period, 23:00 – 7:00h. For the day and evening periods, limits are: $L_{k,d}$; $L_{k,e} \le 35$ For living rooms in dwellings. Limits for the night period, 23:00 – 7:00h. For the day and evening periods, limits are: $L_{k,d}$; $L_{k,e} \le 40$ Limit value $L_k = L_{A,eq,T}$ + corrections for background noise, tonal, impulsive and LF noise
Turkey	[21]	ISO 10052 or ISO 16032	$L_{A,eq,nT} \le 30$ $L_{A,eq,nT} \le 35$ $L_{AF,max,nT} \le 34$	+	Limit for continuous noise in bedrooms during night-time, 23:00 – 07:00. Limit for continuous noise in living areas, kitchen - during 24 hours. Limit for intermittent noise.
(1) Overview information only. Detailed criteria and conditions are found in references. (2) Limits in (brackets) = Recommendation.					

Since it is important to get reliable results, the test methods ISO 10052 and ISO 16032 have requirements for instrumentation [11], [12], [13].

2.2 Ventilation noise limits in Denmark & test procedure

In DK, the building code guideline [4] refers to ISO 10052 [7] 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. [14]. The microphone is placed as indicated in Figure 1, implying that noise from the ventilation system is dominant – and noise from other parts of the room less dominant.

The Danish classification standard [15] for dwellings has six classes A-F for ventilation noise with limits starting with 20 dB in Class A and 5 dB steps between classes up to Class E. Class F has no limit. Minimum Class C with limit LAeq ≤ 30 dB is required by the Danish regulations. However, 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 [2] with an upper limit 25 dB, i.e. 5 dB stricter than regulations. The purpose is to test the feasibility of measuring and implementing 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 [7], 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 [8], [9] (allowing background noise correction) or update the national guideline [14], so correction for background noise can be made, which the authors have previously tested, cf. [6]. However, it would be more optimal to revise the ISO standards aiming at optimizing the procedure for ventilation noise measurements, including also specific microphone positions for such tests.

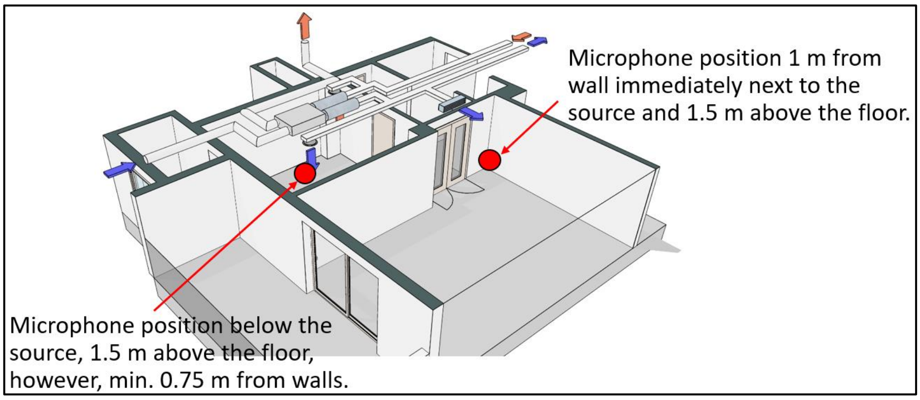

Figure 1: Microphone positions for measurement of ventilation noise according to the national guideline SBi 217 [14] in DK. Illustration copied from from InterNoise2022 paper [5] Fig. 2.

3 Overview obstacles for field tests of low levels of ventilation noise

According to consultants' experiences from field measurements of ventilation noise, the two major obstacles are about too high or disturbing background noise and about adjustment of operating conditions to be well-defined and corresponding to the building code requirements for ventilation. The two test methods, ISO 10052 and ISO 16032, both have clauses (8 and 10, respectively) specifying the required contents of test reports. Both methods request information about operating conditions and background noise (in ISO 10052 just information, since correction is not done) – in addition to the usual requested contents of field test reports about test object, rooms, address, operator etc. Field tests of ventilation noise have become more complicated with automated control of the ventilation systems because description and adjustment of the operating conditions might require a ventilation expert, who may need to be present during tests.

Several other issues are important as reflected in the requirements for the test reports. Correct measurements of ventilation noise have several pitfalls, which less experienced operators may not be aware of, e.g.:

- Does the instrumentation meet the IEC criteria included in the normative references??
- Instrumentation capable of measuring low SPL and all relevant frequency bands with sufficient accuracy?
- Expertise of operator (test method, ventilation systems)
- Calibration of test instruments.
- Quality of test reports.

The challenges are relevant for test of ventilation noise for systems meeting the current noise limit – DS 490 Class C – but become even more important for lower noise limits $L_{Aeq} \leq 25$ dB like in FBK8. The FBK8 limit is the same as in DS 490 [15] Class B. The challenges do also appear in other countries, and acoustic classes for ventilation noise are also included in the international specification ISO/TS 19488 [16], which has ventilation noise class limits similar to DS 490.

4 Pilot test procedure for field test of ventilation noise

Test procedures compensating for the shortcomings of the basic test procedures for measurements of low sound pressure levels are called for. One potential procedure might be to increase temporarily the airflow during the test, implying much higher nose levels and thus less sensitivity to background noise, and then subsequently adjust the noise level to fit the nominal air flow, before reporting. Below is described a potential new procedure, primarily supposed to be applied in combination with ISO 10052 [7] and SBi 217 [14]. The procedure is ideal for a measurement system that enables measurements in two microphone positions simultaneously, but the method can also be used serially if the noise is stationary. In that case, it is important to precisely mark the microphone positions so these can easily be found again. For example, two microphone stands can be used, cf. Figure 2. The method requires the possibility of adjusting the ventilation setting to increased air flow that provides a substantially higher SPL in the microphone positions. In the following, the procedure is referred to as Pilot Test Procedure (PTP).

- **Step 1:** The measuring point defined in SBi 217 is marked so it can be found again – hereinafter referred to as MP1.
- **Step 2:** A new measuring point is marked approx. 25 cm from the ventilation exhaust opening in the direction towards MP1. This new point is referred to as MP2 hereafter.
- **Step 3:** Adjust the ventilation system to operate in the setting with maximum air flow.
- **Step 4:** Perform a measurement in both microphone positions MP1 and MP2 and find the arithmetic difference between the two spectra.
- **Step 5:** Perform a measurement in MP2 with the ventilation system being adjusted to a setting that fulfils the ventilation requirements in the national regulations, in Denmark building regulations [3], Ch. 2 Ventilation.
- **Step 6:** The calculated difference in step 4 is subtracted from the noise level measured in step 5 which yields the new measurement result.

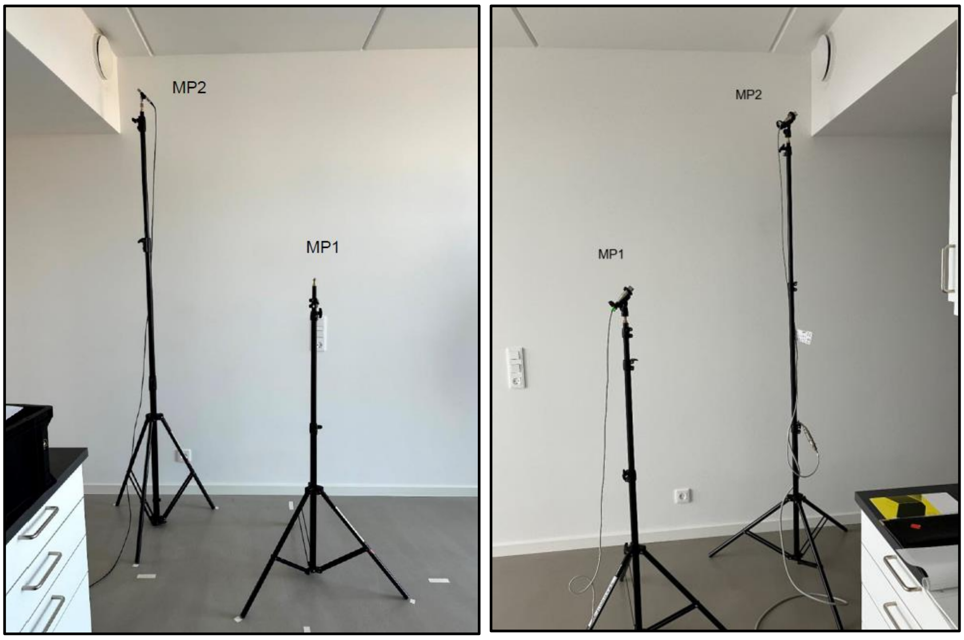

Figure2: Microphone positions for pilot test 1 (25/1-2024) and 2 (21/3-2024).

5 Preliminary pilot study of field test procedure with increased air flow

In a pilot study, ventilation noise tests were conducted according to the procedure described in Section 4 with measurements in two apartments over two days (25/1-2024 and (21/3-2024). The apartments were in a new multi-storey housing (Akademivej 1E, 2800 Kongens Lyngby) known by KAB (building association). The upper limit for ventilation noise was 30 dB as required in new-build (and not the lower FBK8 limit, since that was not the goal). In the first pilot test the noise level was measured with 3 different ventilation settings having different air flow rates. Unfortunately, no background noise could be measured due to frequent external noise disturbances from various construction activities and a time limited access to the apartment. Pilot test 1 was performed with a one-microphone system using a B&K type 4189 ½" transducer (only one microphone was used due to technical issues with cables and connections). In the second pilot test the noise level was measured with 2 different ventilation settings having different airflow rates, and background noise was also measured. Pilot test 2 was performed with a two-microphone system using B&K type 4144 1" transducers. Both pilot tests were performed in the same building in apartments with identical layout (mirrored) and Dantherm HCC 360P2 ventilation units. All measurements were performed with a B&K type 2270 sound level meter and calibration made with B&K Type 4231 calibrator. No reverberation time measurements were performed in either of the pilot tests since the rooms were unfurnished corresponding to the condition for the Danish limit value. The setting with the highest air flow (and highest noise level) is called Setting 4.

Information about different ventilation settings is presented in Table 2. The results of the measurements are shown in Figure 3, Figure 4 and Table 3.

In Figure 3, the directly measured results are shown. As can be seen, for pilot test 2 there were challenges with background noise during the measurements, both as a general high level of background noise and as interrupting short term background noise. For both pilot tests the difference between Setting 4 and Setting 2 is generally between 10-30 considering 1/3 frequency bands and more than > 25 dB for the total level. For pilot test 1 there is basically no difference between the noise level for Setting 2 and 3 for frequencies higher than 800 Hz, and it is assumed that for these frequencies what is measured is the background noise level. This hypothesis is supported by pilot test 2 where the background noise level is identical with the noise level measured in Setting 2 for frequencies above 630 Hz.

Table 2: Ventilation settings of Dantherm HCC 360P2 unit.

Ventilation setting (VS)	Description	Other info
VS1	Lowest airflow rate	Noise levels were not measured
VS2	Automatic setting	
VS3	Medium airflow rate	
VS4	Maximum airflow rate	

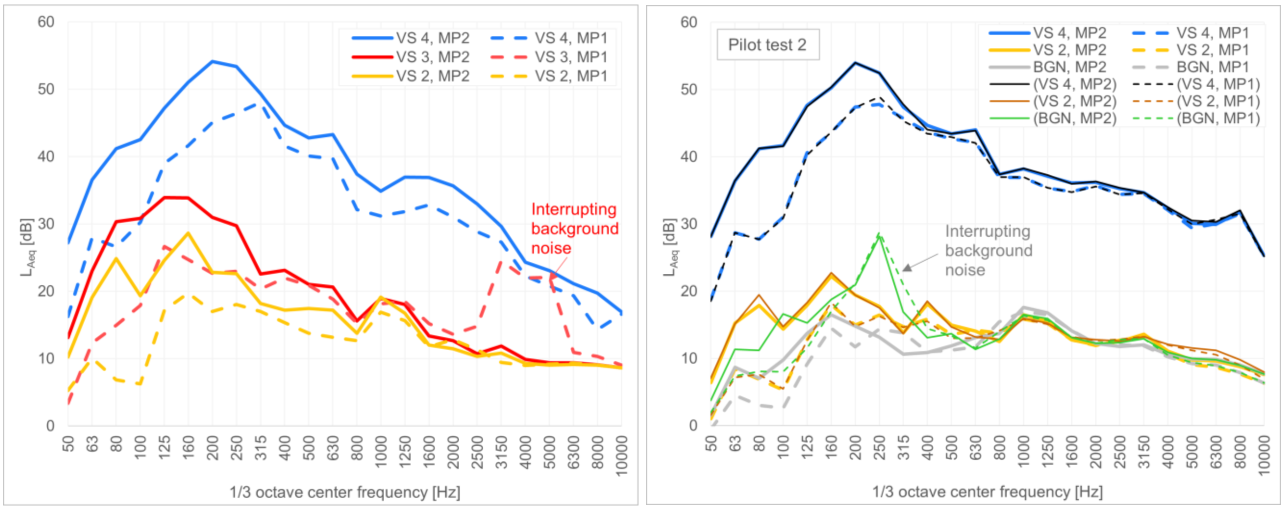

Figure 3: Measured background (BGN) and ventilation noise levels for different ventilation settings (VS) for pilot test 1 (on the left) and 2 (on the right) in microphone positions MP1 and MP2. Brackets indicate repeated measurements.

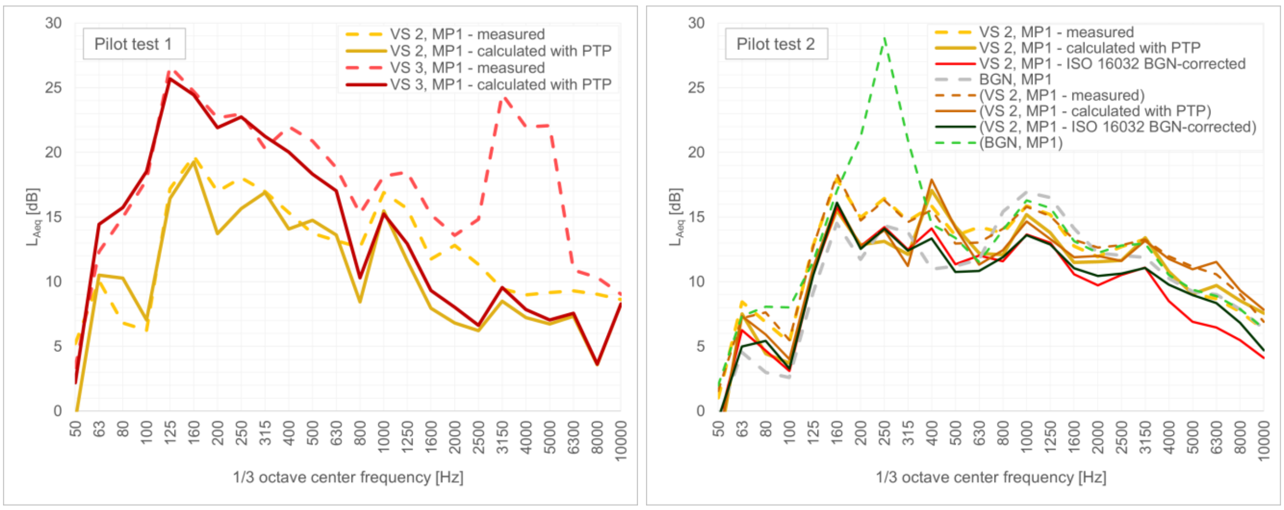

Figure 4: Ventilation noise levels in ventilation setting "VS 2" in microphone position MP1 – measurements and calculations according to the pilot test procedure (PTP) for pilot test 1 (on the left) and 2 (on the right). Brackets indicate repeated measurements.

Figure 4 shows both the direct measurements and the calculated results according to the pilot test procedure, all for MP1. The left side of the figure shows the results for pilot test 1, where a very good correlation between direct measurement and calculated result with the pilot test procedure is seen below 400 Hz for the Setting 3, which is probably due to low or no influence from background noise. A decent correlation between direct measurement and calculated result for Setting 2 is seen below 800 Hz, which is probably due to some influence from background noise. Above 630 Hz there is not much correlation between direct measurement and calculated result, but this is also the frequency area where it is expected that what is measured is primarily background noise.

The right side of the figure shows the results for pilot test 2, where for this measurement there is not much difference between background noise and measured noise, and where the measured noise for frequencies below 800 Hz is lower for pilot test 2 than for pilot test 1. Included on this figure is also the ISO 16032 background noise corrected level, where in general the ISO 16032 background noise corrected level is lower than the calculated level with the pilot test procedure.

In Table 3 the total ventilation noise levels for the two case studies are listed, both as direct measurements and calculated with the pilot test procedure (PTP), either based on 1/3 octave values or single number values. The results corrected for background noise according to ISO 16032 are shown as well. When comparing the calculated results with the pilot test method based on 1/3 octave band or based on single number, a difference between -1.1 dB to +2 dB is seen.

From the table, the following can be concluded:

- The calculated values are always lower than the measured values.
- The results corrected for background noise in 1/3 octave bands according to ISO 16032 are on the same level or slightly lower than the results calculated with the pilot test procedure.
- The variation between the calculated results with the pilot test procedure based on 1/3 octave bands and single numbers is too large, and the pilot test procedure based on 1/3 octave bands should be the preferred one.

Table 3: Total ventilation noise for frequency range 50 to 10 000 Hz in microphone position MP1 – measured, calculated according to the PTP method in 1/3 octave bands, calculated according to the PTP method in single number values. The results to be compared with limits are those in the column with heading Setting 2.

Ventilation settings in columns to the right **Description of tests below:**	Setting 4, L_{Aeq} [dB]	Setting 3, L_{Aeq} [dB]	**Setting 2, L_{Aeq} [dB]**	BGN noise L_{Aeq} [dB]
Pilot test 1 (25/1-2024)				
Measured	53.2	34.2	**27.9**	
Calculated (PTP – 1/3 octave)		32.0	**26.5**	
Calculated (PTP – single-no.)		34.0	**27.5**	
Pilot test 2 (21/3-2024)				
Measured	54.4		**27.0**	25.9
Calculated (PTP – 1/3 octave)			**25.9**	
Calculated (PTP – single-no.)			**24.8**	
Calculated (BGN-corr. 1/3 oct. ISO 16032 method)			**24.8**	
Pilot test 2 repeated – See brackets below:				
(Measured)	54.6		**27.1**	31.4
(Calculated (PTP – 1/3 octave))			**26.2**	
(Calculated (PTP – single-no.))			**25.3**	
(Calculated (BGN-corr. 1/3 oct. ISO 16032 method))			**24.9**	

The results from tests with the suggested procedure seem promising, but further studies are necessary since only two pilot tests were possible in the pilot study. More investigations need to be done, including tests of other types of ventilation systems.

6 Summary, conclusions and recommendations

A pilot study consisting of ventilation noise tests in two new apartments have been carried out to evaluate the feasibility of a suggested new procedure for measuring low noise levels from ventilation systems. The results from the pilot tests with the suggested procedure seem promising, but further studies are necessary since there were just two pilot tests. More investigations need to be done, including tests of other types of ventilation systems. The suggested procedure applies an additional microphone position and the ventilation system adjusted to higher air flow levels, thus creating considerably higher noise levels, and a subsequent adjustment to the normal air flow is made to get the ventilation noise level to be compared with the limit value in the regulations or even lower limits, aiming at establishing less noisy living rooms.

According to consultants' experiences from field measurements of ventilation noise, the two major obstacles are about background noise and about operating conditions to be well-defined and corresponding to the building code requirements for ventilation. Background noise correction is necessary for measurement of ventilation noise, especially for low levels.

Improved/innovative test procedures are needed for measurements of ventilation noise, especially for low noise levels limits ~ 25 dB, but also for higher limits like e.g. 30 dB. In the pilot study was tested one new procedure with increased air flow, which resulted in a ventilation noise level increased considerably, > 25 dB (broadband).

In the future, wider research studies could also include issues like instrumentation and applicability of both simple and complex objective methods for adjustments for tonality, impulsivity and low frequency contents.

For more discussion of ventilation noise tests according to the ISO methods, see results from a previous case study in [6], which also includes reverberation time measurements.

Other issues that could become relevant in practice are applicability and shortcomings of noise measurements with smartphones, which some people consider acceptable for the field tests – probably because they are not aware of that requirements for procedures and instrumentation in the ISO and IEC standards are not fulfilled.

Furthermore, it could be useful to make recordings of ventilation noise stimuli for demo purposes and future laboratory listening tests.

Acknowledgements

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