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Reducing ventilation noise levels from MVHR systems in housing – Challenges and feasibility of field tests

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ABSTRACT

In Denmark - and probably most countries in Europe - regulatory noise limits apply for noise from ventilation systems in housing. During the last few decades, mechanical ventilation with heat recovery (MVHR) has become increasingly prevalent in new and retrofitted housing in Europe, and such systems may operate continuously 24 hours/day and transmit noise into and between rooms. In practice, many people get annoyed or disturbed by the noise during night or when having quiet activities. Many people complain about the noise, and some people change the operation of the MVHR system or even destroy the system. For new-build and new systems in renovated housing, the ventilation system must comply with a noise limit, $L_{Aeq} \leq 30$ dB in dwellings, measured and documented using a simplified version of ISO 10052. Due to dissatisfaction from occupants, it is considered reducing the limit to $L_{Aeq} \leq 25$ dB in living and sleeping rooms, which is currently tested in a voluntary sustainability class (in Danish abbreviated FBK), including use of ISO 16032 for correction of background noise. This paper describes results from a case study comparing the methods and other challenges, when measuring low ventilation noise levels, aiming at providing input for a revised field test method to be applied in the Danish regulations.

Keywords: ***ventilation noise, MVHR, field tests, applicability of methods, ISO standards***

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1. INTRODUCTION

For decades, energy savings for housing has had a high priority for new-build as well as renovation. The need for energy efficient housing combined with the focus on indoor air quality has led to increased use of MVHR systems in dwellings across Europe. Airflows are supplied through ductwork to rooms and extracted from toilet rooms and kitchens by means of a heat recovery unit which works continuously, 24 hours a day at different speeds providing the correct airflow. However, noise produced by the MVHR unit can be transmitted through ductwork to noise sensitive rooms such as living rooms and bedrooms. Furthermore, the ventilation ducts may reduce the sound insulation between the rooms.

Previously – before the increased use 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 the MVHR system. Research studies and experience have shown, that whenever ventilation systems are perceived as noisy, occupants may try turning the system off, resulting in an inadequate air flow rate and a health risk, or maybe even damage the ventilation system. Another disadvantage of many MVHR systems is the poor sound insulation between rooms internally in dwellings, if damping of the ducts is missing, thus leading to annoyance and lack of privacy.

In Denmark, the building code [1] has a Ch. 17 about acoustic conditions. Specific requirements are found in the related guideline [2]. Test conditions are described in [6].

A comparative study of the requirements in eight selected European countries for indoor service equipment noise levels, focusing on ventilation noise was recently performed

[9]. 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 paper [9] showed that most countries have different descriptors (metrics). In addition, several countries apply corrections for tonal noise, impulsive noise and low frequency noise. The comparison between countries indicates that it would be useful to collect experiences with national test procedures, at least for measurements of low noise levels. Many ventilation systems operate automatically, but to get reliable and reproducible test results for comparison with requirements, it is of high importance that a field test is carried out after the adjustment of the system and that the settings and operating conditions are described in the test report. Thus, both ISO 10052 [3] and ISO 16032 [4] should be revised and require clear information in the test reports about these issues during the test. A revision of ISO 16032 has started early 2022, and it would be beneficial to make sure that the procedure for ventilation noise is evaluated carefully, considering the number and positions of microphone positions and the extent of documentation in test reports, which should provide more information about the test, e.g. temperature, humidity, date and results of the system adjustment and preferably airflow rate. It is highly recommended to have a standardized form for expressing 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.

2. THE DANISH REGULATIONS FOR VENTILATION NOISE

In DK, the building code guideline BR2018 [2] refers to ISO 10052 for measurement of service equipment noise, but for ventilation noise (noise source in the room, where the measurement is made), the test procedure in SBi217 [6] prescribes just one microphone position for each source. The microphone is placed as indicated in Figure 1, implying that the noise level from the ventilation system is dominant and less influenced by other noise sources.

The Danish classification standard DS 490 [7] for dwellings has six classes A-F in general, but five classes A-E with limits 20-40 dB for service equipment noise. Since many people are disturbed by ventilation noise during sleep and quiet activities, even if the building code requirement 30 dB (corresponding to Class C) is fulfilled, it has been considered to make the ventilation noise limit 5 dB stricter (Class B) to get quieter living rooms and bedrooms and thus create a healthier indoor climate.

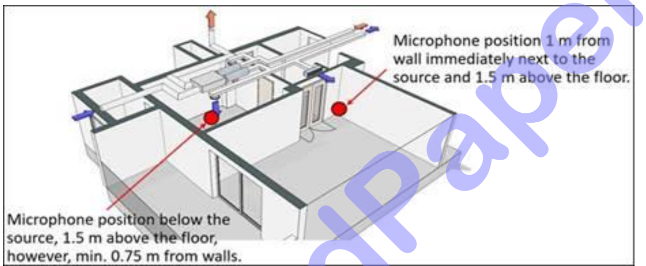

Figure 1. 3D sketches of the setup of MVHR system in a random flat, showing the microphone positions according to SBi 217. Figure from [9].

As a starting point, a voluntary sustainability class for ventilation noise in dwellings has been introduced in FBK [8] 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 the uncontaminated low levels of ventilation noise, even if the microphone position is quite close to the source.

In DK, it is considered either to switch to ISO 16032 (allowing background noise correction) or update the national guideline SBi217 to allow correction for background noise. 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, and for ISO 10052 to allow correction for background noise.

2.1 Ventilation settings

In SBi217, it is in general prescribed (except for schools) for test of installation noise: *"Noise from installations is generally to be tested in the noisiest setting"* and for cooker hoods: *"A cooker hood is set in position 'control ventilation' (lowest setting) at the cooker hood control panel."*

The test conditions are defined several years ago, before modern ventilation systems like MVHR were invented. For FBK, the test conditions are defined in the same way.

3. STANDARDIZED TEST METHODS

Below are described the main features of the two ISO methods ISO 10052 [3] and ISO 16032 [4]. Further comments about advantages and disadvantages of the two methods are described in Section 4.

3.1 ISO 10052

The ISO 10052 method for measuring the sound pressure levels from service equipment is a survey method. According to this method, the SPLs are measured and a voluntary reverberation time correction is applied based on either tabulated values in the standard or measurements according to ISO 3382-2 [5]. No background noise correction is applied. The SPLs are measured in two microphone positions: In one corner position, preferably 0.5 m away from the room surfaces, and in one reverberant field position in the central area of the room with one and two measurements in those positions, respectively. The results are given as weighted energy-average of the three measurements.

3.2 ISO 16032

The engineering method of ISO 16032 entails a more complicated measurement procedure to determine the noise levels of service equipment in buildings. Similarly to ISO 10052, one corner position is used, but two different reverberant field positions are required. When the noise source is in the room, e.g. ventilation grille, an additional microphone position in front of the noise source is required. The measurements shall be performed in octave bands while ISO 10052 enables automatic integration in the required frequency range, yielding only a single-number result. Most importantly, an additional process of selecting the corner position with the highest SPL is undertaken and the number of measurements in each microphone position depends on the difference between two consecutive measurements. Moreover, compulsory background noise measurements and corrections are required. The correction for reverberation time is voluntary and based on measurements according to ISO 3382-2. ISO 16032 requires that the person performing the test should stay out of the test room.
The additional corner position selection, number of microphone positions and requirement for background noise measurements make tests (and subsequently analysis) according to ISO 16032 more time-consuming and noise sensitive. Difficulties arise in finding quiet periods with sufficiently low background noise (traffic, building habitants etc.), especially for lower ventilation noise limits. Requirements for traffic noise levels should always be considered, while setting requirements for noise from technical installations.
Both ISO 10052 and ISO 16032 cover the same frequency ranges and require use of same operating conditions and cycles for mechanical ventilation noise measurements.

4. CASE STUDY

As mentioned previously, issues have arisen with using the SBi217 method for FBK due to background noise. Thus, it was decided to do a case study with detailed measurements by the different methods. The purpose of the measurements was to compare the differences, advantages, and practical limitations of these methods and to determine the challenges of measuring low noise levels. The measurements were performed on 8 December 2022. The measurements were made in a 4-storey apartment building in the Odense area. Most of the renovation was completed, but there were still some activities during day time.
The ventilation noise measurements according to the measurement methods of ISO 10052, ISO 16032, the Danish SBi 217 and FBK were performed in a newly renovated apartment building with a new decentralised mechanical ventilation system with different operation settings available.
The measurements were carried out during evening-time to reduce the influence of traffic noise and disturbances from the craftsmen in the building. As per the requirement of ISO 16032, there were no operators present in the room during the measurements.

4.1 Setup

The primary measurements were performed in two unfurnished rooms each having a supply air grille as a noise source - a smaller room and a living room shown in Figure 2. The ventilation noise was measured for the “Default”, ”Out of house” (no people at home) and “Maximum” ventilation settings. The ventilation rate for “Out of house” is lower than for “Default”. The measured air flow rates for the “Default” setting in the living room and small room are 14 and 23 m^3/h respectively (designed to 15 and 24 m^3/h). Background noise (B2) and reverberation times (RT) were measured in both rooms.
The microphones are placed as indicated in Figures 3-5.
The locations of different microphone positions were chosen according to the requirements of the methods described in Section 2 and Section 3 and can be seen in

Figure 3 top and bottom for the living room and small room respectively.

The A-weighted equivalent sound pressure levels were measured with a single ½" B&K microphone of type 4189, fixed on a tripod, and a B&K 2250 sound level meter (SLM). The residual noise measured with the microphone is approximately 18 dB(A), and the diffuse field correction was applied for measurements in these rooms. The measurements were performed successively in different microphone positions with an averaging time of 30 seconds per position. Each measurement was listened to by the operator, and if disturbed, the measurement was repeated. The measured ventilation noise is evaluated in the frequency range of 63-8000 Hz. The interrupted noise method was used for RT measurements.

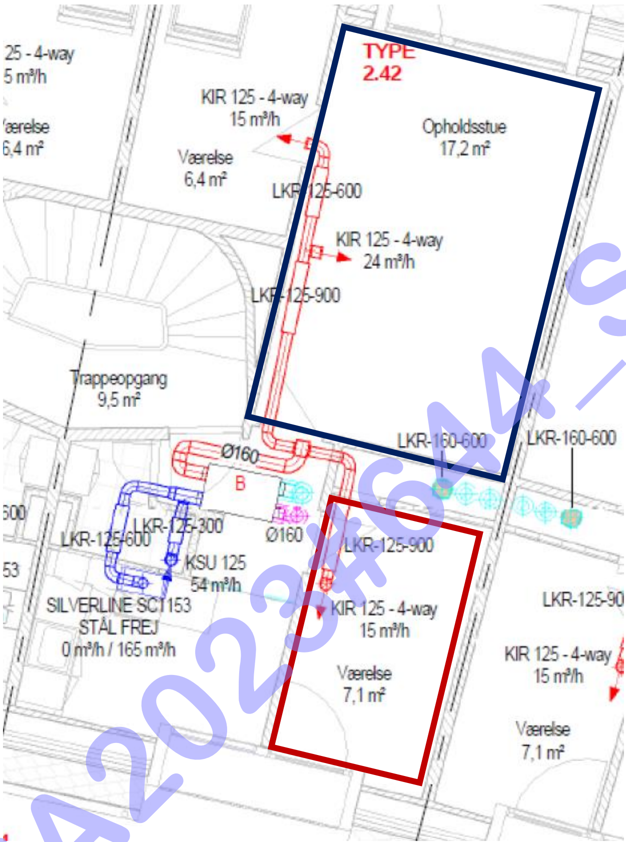

Figure 2. Layout of the case study apartment, with a ventilation aggregate in the hallway. - The light blue lines mark the exhaust air ventilation, and the light red lines mark the supply air ventilation. Living room marked with a dark blue rectangle, small room marked with red rectangle. The façade in the small room is exposed to traffic noise.

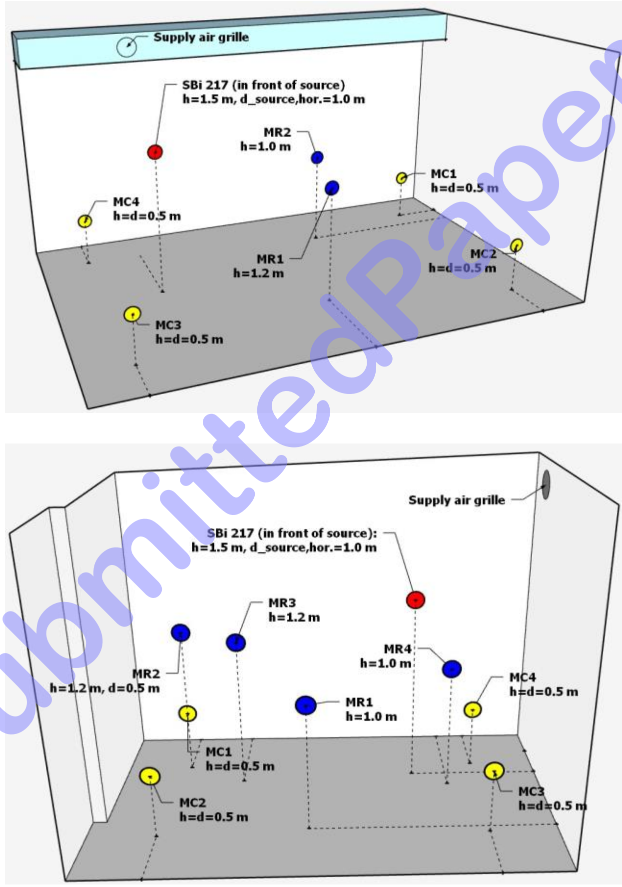

Figure 3. 3D sketches of the measured rooms with different microphone positions. Top – living room, Bottom – small room. The blue 'MR1-MR4' mark positions in the reverberant field. The yellow 'MC1-MC4' mark the corner positions. The red marks show the SBi 217 positions.

Figure 4. Photo of the living room with supply air grille and the SBi217 microphone position.

Figure 5. Photo of the small room with supply air grille and the SBi217 microphone position.

4.2 Comparison of results

The measured ventilation noise levels according to different methods with and without B2 and RT corrections are given in Tables 1-3. The small room was too small to properly follow all guidelines for microphone positioning, and two interpretations for microphone positioning were performed leading to two different results as can be seen in Tables 1-3 for column "ISO 16032" and row "Maximum ventilation". The same positions were used for the default ventilation setting but did not lead to two different results.

For the measurement following ISO 10052, fewer microphone positions are needed than for ISO 16032. However, results with all relevant combinations of microphone positions were calculated anyway and the resulting range of results is shown in the column "ISO 10052" in Tables 1-3.

When comparing the results in Table 1, the results following SBi 217 and ISO 16032 are nearly identical, even though the SBi 217 is based on one microphone position and the ISO 16032 is based on 3 well selected microphone positions. Interestingly, the difference between ISO 10052 is a little larger and is probably because of unfortunate combinations of microphone positions.

For Table 2 (all with the background noise correction from ISO 16032) the results with the three methods are nearly identical except for the results with the default setting in the small room, where there are some variations. Background noise issues are prevalent for ventilation settings "Default" and "Out of house" at 500-8000 Hz, 63 Hz and partly at 250 Hz, which is marked with an '*' in Tables 2 and 3.

Table 1. Measured A-weighted SPL of ventilation noise according to SBi 217, ISO 10052 and ISO 16032 *without* B2 and RT corrections.

Room	Ventilation setting	SBi 217 [dB]	ISO 10052 [dB]	ISO 16032 [dB]
Living room	Default	24	23-24	24
Living room	Out of house	23	23-24	23
Living room	Maximum	45	44-45	45
Small room	Default	31	28-31	30
Small room	Maximum	54	52-54	53-54

Note: The results are without B2 and RT corrections.

Table 2. Measured A-weighted SPL of ventilation noise according to SBi 217, ISO 10052 and ISO 16032, all with the ISO 16032 B2 corrections.
* measurements affected by B2 noise.

Room	Ventilation setting	SBi 217 [dB]	ISO 10052 [dB]	ISO 16032 [dB]
Living room	Default	22*	22*	22*
Living room	Out of house	21*	21-22*	21*
Living room	Maximum	45	44-45	45
Small room	Default	31*	28-31*	29*
Small room	Maximum	54	54	53-54

Table 3. Measured A-weighted SPL of ventilation noise according to SBi 217, ISO 10052 and ISO 16032, all with ISO 16032 B2 corrections and method-specific RT corrections.
* measurements affected by B2 noise.

Room	Ventilation setting	SBi 217 [dB]	ISO 10052 [dB]	ISO 16032 [dB]
Living room	Default	19*	19*	18*
Living room	Out of house	20*	18-19*	17*
Living room	Maximum	42	40	39
Small room	Default	28*	24-27*	26-27*
Small room	Maximum	51	50	49-50

4.3 Correction for background noise in octave bands and residual noise

The background noise corrections in Tables 2-3 are applied in octave bands. According to ISO 16032, the measurements are deemed to be affected by the background noise if the difference between the measured ventilation noise is ≤ 4 dB. The measurements with the Default and "Out of house" settings in Tables 1-3 were affected by the background noise and the maximum 1.3 dB correction was applied to affected frequency bands. As lower and lower ventilation noise levels are desired, it can be expected that the background noise affects an even higher number of ventilation noise measurements. This could mean that most of the measurements will be carried out during night-time in the hope of low background noise levels, causing inconvenience for acoustic consultants and technicians and increased costs for clients. Provided that the background noise levels are still not sufficiently low, a note of "Measurements were affected by background noise" shall be added to the report and legal questions of the "correct" ventilation noise levels might arise. Furthermore, for measurements of low noise levels, the residual noise of the measuring systems should be monitored and regulated, as it can occur that the measured background noise is lower than the residual noise of the measurement system. For the current case study, the residual noise affected all the background noise levels, but also ventilation noise levels for Default and "Out of house" settings at 1000 Hz and above, in spite of using high-end measuring equipment. -

4.4 Correction for background noise in single number values

In contrast to ISO 16032, the FBK method allows B2 background noise correction to be applied in single-number values, resulting in differences in corrected noise levels compared to when the background noise is corrected for in octave bands. Six supplementary ventilation noise measurements were done in other rooms in the building following the SBi 217 methodology. The free field microphone correction was applied during the measurements. The differences in the calculated B2 corrected ventilation noise results for these six different rooms in the same apartment building using the Default ventilation setting can be seen in Table 4.

The results in Table 4 show that correcting for background noise in single-number values can result in up to 1.4 dB lower ventilation noise levels compared to when corrections are performed in 1/3-octave bands, highlighting the importance of the specification of the background noise correction process in the suggested new Danish regulations.

Table 4. Measured A-weighted SPL of ventilation noise calculated from 1/3-octave band results, 63-8000 Hz. Measurements according to SBi 217 in one microphone position in six different rooms in the apartment building.

Meas. no.	Vent. L_{Aeq} [dB]	B2 L_{Aeq} [dB]	Δ [dB]	B2-corrected ventilation noise Single-no. [dB]	1/3 oct. [dB]	Δ [dB]
1	27.6	22.9	4.8	25.8	26.4	0.5
2	22.6	20.9	1.7	20.4	20.8	0.5
3	22.8	19.1	3.7	20.6	22.0	1.4
4	23.1	22.4	0.6	20.9	20.9	0
5	25.9	23.5	2.3	23.7	24.5	0.8
6	27.2	21.6	5.6	25.8	26.2	0.5
Log. avg.	25	22	3	23	24	1

4.5 Correction for reverberation time

Although current service equipment noise requirements in Denmark are set for unfurnished rooms, the appropriateness of the reverberation time correction is relevant to discuss. The difference of the different RT corrections is shown in Table 5.

Table 5. RT correction from an unfurnished room to a standardized furnished room according to different methods.

Room	Ventilation setting	SBi 217 [dB]	RT measured [dB]	RT table values [dB]
Living room	Default	-3	-3	-4
Living room	Out of house	-3	-3	-4
Living room	Maximum	-3	-5	-6
Small room	Default	-3	-3	-3
Small room	Maximum	-3	-4	-4

The SBi 217 instruction treats all rooms equally by adding a correction of 3 dB, when converting from furnished to unfurnished rooms. The RT corrections according to ISO 16032 and ISO 10052 methods normalize the room to have the standardized RT of 0.5 seconds, whereas in both ISO 10052 and ISO 16032 corrections can be based on measurements. However, for ISO 10052 corrections can also be based on tabulated values depending on the room volume and the room surfaces. The corrections according to the two standards range from -3 to -6 dB, while being slightly higher for the ISO 10052 method when using the tabulated values. The reason that the corrections vary within method for different ventilation settings for ISO 16032 and 10052 is that the octave band spectra of the noise vary depending on ventilation settings, and since the RT correction is also applied in octave bands, the resulting summed levels change.

4.6 Overall duration of measurement

Another important aspect to comment on is the duration of measurements for different methods. For SBi 217 one microphone position is sufficient. For ISO 16032 three microphone positions are sufficient, but these are selected based on 7-8 measurements. For this detailed case study, an entire evening was spent in only two rooms with multiple ventilation settings. For a traditional SBi 217 measurement this could have been completed much faster.

4.7 Specifying the ventilation setting

The Danish SBi 217's requirement of the "noisiest setting" during field compliance test calls for comparison of the measured "Maximum" setting levels to the current requirements. Consequently, the current applicable noise limit $L_{Aeq} \leq 30$ dB is exceeded by 15 dB in the freshly renovated living room and 24 dB in the small room as seen in Table 1. If for example measurements in "Default" setting would be required, then the measured ventilation noise in the living room would comply with the requirements and exceed the requirement by 1 dB in the small room (Table 1). A discussion of how to legislate and phrase the requirements is necessary, whereas the solution of linking the required measurement's ventilation setting to the designed airflows in the rooms is recommended.

5. DISCUSSION ABOUT REVISION OF DANISH REGULATIONS FOR VENTILATION NOISE

A meeting was initiated by the Danish Acoustical Society in January 2023 to discuss FBK and the issues raised in this paper. Preliminary results of the case study were presented together with presentations about the regulations and other input about ventilation noise measurements. The meeting was well attended (40 participants) with interesting discussions. On one hand, precise and correct results are desired; on the other hand, it is also important that the measurements can be handled relatively easily to keep the price low. Quality of measuring equipment was also discussed, since it affects how low values can be measured. One argument for not lowering the noise limit was that it would require substantially more expensive equipment. For the case study, it was chosen to use a B&K 2250, which is a high-end measuring equipment fulfilling the SLM specifications in SBi 217 and applied by many acoustic consultants in Denmark. However, as described, the residual noise of the equipment did influence the measurement, even with high-end equipment. It is of course possible to acquire equipment with lower residual noise, but not necessarily with standard equipment.

For a suggested revised Danish regulation, comparisons of results with ISO 16032 and SBi 217 in Tables 1 and 2 are relevant. They provide nearly identical values, but it cannot be said whether the ISO 16032 method is superior or inferior to SBi 217. However, based on the detailed case study, it seems justified to keep the SBi 217 methodology, but we suggest including the background noise correction as in ISO 16032, preferably with correction in 1/3 octave bands. The current Danish regulation is based on unfurnished rooms and as such there is no need for correction of reverberation time in this case study. However, if correction is necessary, it should be based on the measured reverberation time.

Penalties for audible tonality and other noise characteristics, which could annoy the residents, have not been described in this paper. They are however important aspects, which should be investigated further, possibly together with new studies on the correlation of annoyance with measured noise levels. Multiple available objective quantification methods already exist, and some are implemented in commercially available sound level meters.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on experience from practice and the case study, it is considered necessary to revise the Danish guideline for field test of ventilation noise, thus allowing correction for background noise. Furthermore, the prescription of test in the noisiest setting seems outdated and should be revised to fit realistic and more typical conditions. It is strictly necessary that the setting of the ventilation system is included in the test report.

In summary, the following changes of SBi 217 [6] are recommended:

- Correction for background noise.
- Setting of the MVHR system for the test situation to be revised to fit realistic and more typical air flow conditions.
- Introduce a test sheet for test of ventilation systems.
- Investigate alternative methods for measuring low ventilation noise levels.

Finally, it would be useful with increased enforcement of regulations, including check of field test reports, since enforcement in the past of sound insulation requirements 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 for those performing the field tests of noise from ventilation systems.

7. ACKNOWLEDGMENTS

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