Questionnaire about Low Frequency Noise measurements in rooms

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Room modes at low frequencies generate large sound pressure level differences within enclosures. The resulting sound field is complicated and the sound pressure level measurements become very uncertain. Consequently, the measurements of environmental noise in dwellings, of occupational noise exposure, and of sound insulation of façades, are not accurate at low frequencies. A special measurement methodology exists in a few countries. Measurement methods aim to be accurate and reliable, but they can not determine, at the same time, both the existing and the experienced sound field. A questionnaire was created to gather opinions on how measurements should be performed from several experts with experience in low frequency noise measurements in rooms. Twenty-three experts took part in this survey. The results from the questionnaire are presented in this paper. Most participants considered it necessary to standardize a reliable measurement method, but there was no unanimity about what the method should be. The most controversial points of discussion were the locations where the measurements should be taken, and how the measured data should be analyzed. A brief discussion of these points is presented.

1. INTRODUCTION

Sound fields in rooms at low frequencies are extremely complicated due to the existence of individual room modes. Room modes, sometimes called standing waves, are the result of the coincidence at a certain point of at least two sound waves. The variation of sound pressure level (SPL) at low frequencies inside the room can be above 20 dB. SPL measurements become uncertain because a measurement at one position, or even at a few positions, cannot sufficiently depict the experienced noise field. The uncertainty of any measurement method is typically determined by two quantities: reproducibility and repeatability. The reproducibility is the difference between successive measurements carried out by different measurement operators. The repeatability is the difference between successive measurements carried out by the same measurement operator, or the difference between measurements performed at the same point. The reproducibility is related to the randomness in the selection of measurement locations, while the repeatability is more dependent on the spatial variation of SPL around the area where the measurement is performed.

Standardized room acoustic and related measurement methods, e.g. ISO 10052 [1], ISO 140 - 4 [2], ISO 354 [3], and ISO 374x series presume that the acoustic field in the room is diffuse; the sound enters any point of the room evenly from all directions (the intensity vector is zero), and the spatial uniformity of SPL is perfect within the room. These presuppositions are fulfilled in typical living rooms quite well above 100 to 300 Hz, depending on the room volume, but they completely fail at lower frequencies.

Some national standard

Table I. Summary of available measurement methods [12, 13]

No	Ref.	Country	Number of measure-ment locations	User or operator locations	Points in corner	Frequency range [Hz]	Minimum distance to walls [m]	Height [m]
1	[4]	Sweden	3	2 user	1 corner	31.5 - 200	0.5	0.6, 1.2, 1.6
2	[5]	Denmark	3	2 user	1 corner	5 - 160	0.5	-
3	[6]	Germany	1	1 operator	-	10 - 80	-	-
4	[7]	Austria	1	1 operator	-	10 - 80		-
5	[8]	Netherlands	1	1 user (or)	(or) 1 corner	20 - 100	0.2 to 0.5	-
8	[9]	Finland	multiple	user	-	20-200	1.0	-
6	[14]	Japan	1	1 user	-	10 - 80	-	-
7	[15]	USA	multiple	-	corner	-	-	-
9	[16]	ISO 16032	3	2 user	1 corner	31.5 - 8000	-	0.5, 1.0, 1.5
10	[11]	Pedersen et al.	4	-	corner	-	0.1	0.1
11	[12, 13]	Oliva et al.	multiple	user	optional	20 - 10000	0.3	0.6, 1.2, 1.55

measurement methods [4-9] include specifications which restrict the locations where the measurements are performed in order to minimize the SPL uncertainty at low frequencies. Simmons [10] compared 24 published measurement methods including specifications for low frequency noise (LFN) measurements. The spatial variation of SPL in ten different rooms was measured along grids of equally distant points at certain heights. Each method was tested in each room by means of its specific instructions on where to put the microphones. The reproducibility of the methods, typically in the order of 15 dB at low frequencies, was unacceptable. Methods where the measurements were carried out close to the geometrical corners of the room had better reproducibility. The results were used to develop Ref. [4] where measurements are performed in three locations; two in locations occupied by the user of the room, and one in the vicinity of a corner. Pedersen et al. [11] recently introduced a new method, the 3D-corner method. Measurements are performed in four three-dimensional room corners with a distance to the room boundaries of 0.1 m. The procedure aims to find the highest SPLs in the room with a high reproducibility. However, the method is not applicable to high frequencies, because the SPL in the corners is greatly influenced by the noise transmission paths. The measured SPL in the corners can be higher than in the locations occupied by the user of the room. Oliva et al. [12, 13] have introduced a general measurement method which focuses on the sound field as experienced. This method is suitable for environmental noise problems and occupational noise evaluation. The complete audible frequency range is measured, and the measurements are always performed at the locations occupied by the user of the room, whether lying, sitting, or standing. A summary of existing measurement methods and their characteristics is presented in Table I.

No compulsory or even informal target values for LFN have been published in the majority of countries. The existing target values that have been published are usually based on the A-weighted SPL. When the intrusive noise has a strong low frequency character, the A-weighted target values are not necessarily exceeded, although the noise might be clearly heard and experienced as annoying. Countries with special measurement procedures

for LFN have also published special target values for LFN in dwellings. A review of measurement methods and target values for LFN was presented in Ref. [13]. Not only are the measurement procedures applied in different countries different from each other, but also the target values and the way the measurement results are interpreted are different.

Manufacturers of industrial devices emitting noise with low frequency characteristics, e.g. wind mills and combustion power plants, do not usually know in advance whether their products will fulfil the noise requirements in the destination country of the device. In environmental noise projects, the expected sound field inside dwellings is calculated from the sound insulation properties of the façade or wall partition. The procedure is, however, not practical at low frequencies because of the existence of room modes. The results presented in Ref. [17] showed that the uncertainty of the sound reduction index, R'_w, is too high when the measurements are performed with the pressure method ISO 140-4 [2]. R'_w depends strongly on the selection of the measurement locations inside the enclosure. When the sound insulation properties of façades are poor, as typically it is at low frequencies, the SPL in some locations inside the enclosure might be as high as outside the building [13]. The uncertainty in the estimation of R'_w entails that the annoyance risk from external LFN inside a building cannot be predicted in advance.

The above-mentioned points were common topics of discussion at the most recent 14th International Meeting on Low Frequency Noise and Vibration and its Control, held in Aalborg in June 2010. Many experts agreed that the situation could be improved, and a more generally accepted and standardized measurement method should be developed.

A project was set up to gather the opinion of several experts with experience in LFN measurements in rooms. A questionnaire was created and distributed through the internet. The questionnaire aimed to inquire about all related topics, and it allowed space for additional comments. Twenty-three experts took part in the experience. The results of the questionnaire are presented in this paper.

2. METHODS

A questionnaire survey was created to gather the opinion of several experts with knowledge of and interest in low frequency noise measurements in indoor spaces. The questionnaire was designed, initially, to be completed in 3-5 minutes. The questions and the space for additional comments aimed to cover all topics and points of interest:

- number and measurement locations within the room
- duration of measurements
- frequency range and frequency bandwidth
- analysis of the results and their presentation
- applicability of the method to different types of noise situations

There were altogether 10 questions. Some questions could be answered by selecting only one option from all the given possibilities (option boxes), while other questions allowed selecting simultaneously several options (check boxes).

The questionnaire aimed to be impartial and not biased towards any existing method. The author of this paper has, however, recently presented a new measurement method [12, 13].

The invitation to participate in the survey was sent to 30 experts in the beginning of October 2010. The participants were selected on the basis of their background. Most commonly, their research or any of their published journal or conference papers have dealt with LFN measurements in rooms.

Table II. The names of 22 participants (out of 23)

Jonas Brunskog	Kari Pesonen	David Waddington
Jorgen Jakobsen	Marianna Mirowska	Paolo Lenzuni
Kai Abrahamsen	Piet Sloven	Carel Ostendorf
Herbert Muellner	Thomas Myck	Johanna Bengtsson Ryberg
Finn Jacobsen	Christian Simmons	Dan Hoffmeyer
Frits van den Berg	Arnold Fuss	Steffen Pedersen
Uwe Ritterstaedt	Pekka Sipari	Martin van den Berg
Geoff Leventhall		

Twenty-three experts completed the questionnaire. The participants were informed that the results, and their opinions and comments, would be treated anonymously. No member of the Finnish Institute of Occupational Health was asked to take part in the questionnaire survey.

3. RESULTS

The time to complete the questionnaire, e.g. the time from the participant opening the link until the form was finally submitted, varied greatly among participants. On average it was 32 minutes. All participants added valuable comments. The names of 22 participants are presented in Table II.

Eleven participants (47.9 %) were researchers, six participants (26.1 %) worked in an administrative position, and nine participants (39.1 %) were acoustic consultants. One participant was both a researcher and an administrator, a second participant was both an administrator and a consultant, and a third was both a researcher and a consultant.

The answers concerning the preferable measurement locations, e.g. where to place the microphone, are presented in Table III. Of the participants, 70 % considered it necessary to perform the measurements in the locations representing the typical use of the room. Three of them recommended, in addition, supplementary and simultaneous analysis in the 3D-corners, whilst another three preferred to perform a simultaneous scan around the middle of the room as is done in ISO 10052. One participant supported a method which considers the three above-mentioned possibilities at the same time (answers 2, 3 and 5 in Table III). Nine participants considered that the measurements should be performed only at the points which strictly represent the typical use of the room. Two participants considered that measurements should be performed only in the 3D-corners. One participant would carry out measurements as in ISO 16032, e.g. one measurement in a corner and two in the reverberant field. One participant would carry out measurements, as suggested by Defra, at the location where the user of the room considers the noise to be most annoying. One participant did not support any of the methods suggested in the questionnaire, but he/she did not specify another possibility. One participant would perform measurements both in an occupant location and scan the room in order to find the maximum SPL. Two participants commented that measurements close to corners should be avoided because they are affected by structural transmission paths.

Table III Answers concerning preferable measurement locations. Three participants chose simultaneously answers 2 and 3. Three participants chose simultaneously answers 3 and 5. One participant chose simultaneously answers 2 and 6, and another answers 2, 3, and 5. Simultaneous answers were allowed

Table III. Answers concerning preferable measurement locations

Answer	Quantity	Per Cent
1. Geometrical centre of the room	0	0.0
2. 3D-corners	7	30.4
3. Points which represent the typical use of the room	16	69.6
4. Any point in the room	0	0.0
5. Scanned average in the middle of the room as in ISO 10052 and ISO 140-5	4	17.4
6. Along a main diagonal through the room	1	4.3
7. None of the above	4	17.4
Total	32	

Table IV. Answers concerning for preferable number of measurements

Answer	Quantity	Per Cent
1. 1	0	0.0
2. 2	2	8.7
3. 3	4	17.4
4. 4	1	4.3
5. As many as required, but at least 3	13	56.5
6. More, how many?	3	13.0

The answers about the preferable number of measurements are presented in Table IV. Of participants, 78 % considered that a minimum of three measurements should be performed. Several participants commented that the number of measurements should be related to the scattering of the results, e.g. the variation of SPL within the room.

Twenty-one participants (91.3 %) considered that the duration of the measurement should be representative of the noise event. Two participants (8.7 %) considered it more convenient to measure for at least 24 hours.

All participants (100 %) would perform the measurements in 1/3-octave bands, i.e. none of the participants considered it appropriate to measure LFN in 1/1-octave bands. Three of the participants suggested that narrower band measurements, e.g. 1/24-octaves or FFT, could be carried out in the cases where tonal noise is suspected to be present.

The answers concerning the preferable measured frequency range are presented in Table V. Two participants additionally commented that there is no necessity to limit the measured frequency range a priori, e.g. the whole audible frequency range is measured and only the frequency range of interest is post-analyzed.

Table V: Answers concerning the preferable frequency range. Other possible ranges, answer 5, were 10-8000 Hz, 8-100 Hz, 8-100 Hz, 4-10000 Hz, 5-5000 Hz, 1-1000 Hz and 10-160 Hz.

Eleven participants (48 %) considered that the target values ought to be stated individually for each frequency, e.g. a reference curve. The

Table V. Answers concerning the preferable frequency range

Answer	Quantity	Per Cent
1. 20 Hz - 10 000 Hz (no distinction between low and high frequencies)	5	21.7
2. 20 Hz - 20 000 Hz (no distinction between low and high frequencies)	1	4.3
3. 10 Hz - 80 Hz (low frequencies only)	1	4.3
4. 20 Hz - 200 Hz (low frequencies only)	9	39.1
5. Other range [Hz]	7	30.4

target value(s) define the SPL which can not be exceeded in the enclosure. Nine participants (39 %) considered it more convenient to use a single number, e.g. L_{Aeq} or L_{Ceq}, both to describe the measured noise and to be used as the target value. Three participants (13 %) thought that both options, e.g. a reference curve and a weighted equivalent level, should be used as target values simultaneously.

Ten participants (43 %) would compare the results from each individual measurement against the target value(s). Two participants (9 %) would calculate the maximum experienced SPL from all measurements, and that value would be compared against the target value(s). Therefore, 52 % of participants considered that the target value(s) can not be exceeded in any measured location of the room. On the other hand, nine participants (39 %) would calculate the power average SPL from all measurements, and then compare that value against the target value(s). One participant suggested that measurements with too low SPL compared to the average should be discarded from the power-averaging calculation. One participant did not indicate what should be done with the measured data.

Twenty-two participants (95 %) agreed that a standardized LFN measurement method should be available. One participant stated that the development of such a method had already been tried in the past with no success.

The participants were asked whether the measurement method they described in the questionnaire could be applied and adapted to several types of noise measurements. The answers to this question are presented in Table VI.

Table VI: Answers concerning applicability of a standardized measurement method. The method should be valid for: Five participants answered that the method should be valid for the three types of measurements simultaneously. Four participants answered that the method should be valid for environmental and occupational noise simultaneously. Four participants answered that the method should be valid for environmental noise and sound insulation measurements simultaneously. One participant did not answer the question.

4. DISCUSSION

The majority of the participants considered that the goal of the measurement method is to present the experienced sound field. Thus, the measurements should be performed only at locations which represent the typical use of the room. A minority of participants, 8 %, considered that the measurements should be performed strictly in the vicinity of the corners, in order to capture the maximum SPL in the room. Pedersen et al. [11] have reported that the power averaged from the measurements in four 3D-corners is usually 4 dB higher than the room's power average. Decreasing the measured SPL in the corners by 4 dB should, consequently, be a good indicator of the experienced sound field. However, it is not possible to predict whether the experienced noise level, e.g.

Table VI. Answers concerning applicability of a standardized measurement method

Answer	Quantity	Per Cent
1. Environmental noise problems in dwellings	19	82.6
2. Occupational noise in rooms	12	52.2
3. Sound insulation measurements (R'w) of facades	12	52.2
Total	43	

on a bed or a sofa, would be lower than or as high as the maximum of the room. Pedersen's method could therefore underestimate the experienced SPL. The scanning method, by contrast, offers poor repeatability, it might overestimate the experienced SPL, and it is impractical in cases with time-variable SPLs. Noise is most annoying typically in locations of relaxation, like on a sofa, bed, or chair. Thus, performing measurements in the places used by the occupant has a higher ecological validity than performing measurements in artificial locations like room corners. From the occupant's psychological point of view, the conclusions based on such measurements may also be more readily accepted and perceived as reliable. In work rooms, like control rooms, measurements at operators' positions only are adequate.

Most participants would perform the measurements in 1/3-octave bands. But there was no unanimity in the results about what frequency range should be measured. Neither was there agreement about how to use or apply the measurement data. Analyzing the individual answers about the preferred frequency range, answer 5 in Table VI, it is seen that 13 participants thought low frequencies should be studied and measured separately from high frequencies. Nor was there unanimity about the frequency range to define "low frequencies", but the 20-200 Hz range was the most often accepted. Seven participants indicated that the lowest measured frequency should be less than 20 Hz. Microphone problems might then appear, which would be a problem for many of the sound-level meters in stock. The standard IEC 61672 allows very large tolerances under 16 Hz. Ten participants stated that all audible frequencies can be measured a priori at once, and according to the results, this is the analysis process that should be adopted depending on the type of noise. Methods which distinguish between LFN and higher frequency noises may be difficult and ambiguous to apply. In the end, they might become more time-consuming because they require an initial measurement and analysis to distinguish the type of noise and the successive measurement procedure which should be undertaken. Measuring all audible frequencies at once, e.g. 20 Hz - 10 kHz, offers important information about the context in which the LFN is present.

Ten participants would compare the measured SPL against a frequency dependent target value, e.g. a reference curve. Nine participants, on the other hand, considered it more convenient to summarize and simplify the measured data to a single number determined by a weighting network, e.g. a C-weighted, A-weighted or Z-weighted equivalent level. Three participants would be more satisfied if both possibilities, e.g. a reference curve and a single number, were available when the measured data are compared against national regulations. It is well known that the A-weighting network is not adequate when low frequencies are of interest [19]; neither the C- nor the Z-weighting network is suitable to express the experienced noise. When the whole frequency range is measured and a single number is desired, it would be convenient perhaps to give both the C- and the A-weighted levels. The difference between the measured SPL applying both networks, L_C-L_A, has been used with relatively good success as an indicator to evaluate the amount of low frequency noise in a certain noise situation [19]. A measurement method, however, does not necessarily define how the results should be interpreted, nor what the target values should be. Each country, for socio-economic-cultural reasons might define its own target values. When the measurement method is designed with care, all possibilities to analyze the data will remain fully open.

5. CONCLUSIONS

Low frequency noise measurements in indoor spaces are uncertain, and there is yet no agreement among countries and experts about how the measurements should be performed. The opinions of 23 experts with experience in the matter were gathered through a questionnaire. There was unanimity about certain topics, while others require further discussion. However, the author of this work considers that to design and to standardize a general measurement method might not be an impossible mission. This work can be used as a foundation for discussion. The establishment of a workshop on this topic would be desirable. The 15th International Meeting on Low Frequency Noise and Vibration and its Control to be held in Stratford-upon-Avon in 2012 would be a perfect place to do so.

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SCHOOL NOISE LEVELS CAUSING TEACHERS' HEARING LOSS

Some teachers in Winnipeg's largest school division are experiencing some hearing loss due to high noise levels in the workplace, according to a recent survey. The Winnipeg School Division tests about 400 teaching and non-teaching staff every year for hearing loss, and officials say this is the first time they have seen a shift. "It's a warning sign to us that we need to do something," Eugene Gerbasi, the division's director of human resources, told CBC News. "If we don't do something, individuals could potentially lose their hearing." The school division conducted a recent survey that found school gymnasiums are the noisiest, at more than 90 decibels. Under Manitoba's workplace legislation, noise levels cannot exceed 85 decibels. Other school areas that scored high noise levels include choir, music and band rooms, as well as industrial arts classrooms. Gerbasi said teachers and staff at Winnipeg School Division will soon have to start wearing protective hearing devices.

NEWCOMERS STOP THE BELLS

When Jonathan Apps and Christina Hallett moved to their dream home in the country last year, they were looking forward to enjoying the good life. But just months later, the couple are embroiled in a row with their neighbours - over a noisy church bell that keeps them awake at night. After voicing their concerns to the council, the church was swiftly served with a noise abatement notice between 11pm and 7am. But because the bell cannot be turned off at night, church leaders have been forced to silence it completely. Angry villagers - including Judith and Phillipe Giorgetti, who run the Golden Lion pub - argue that the bell chimes, which take place every 15 minutes, are 'part of the village'. And warden John Ledbury, whose house backs on to All Saints Church, said: 'It is a very sad situation. 'One person comes into the village and without any reference to the church has decided to go to the council.' Mr Ledbury said the church, in Wrington, Somerset, was hoping to appeal the noise abatement notice. Mr Apps maintains that he and his partner 'merely reported' their concerns about the church to the council. 'It is the council taking action, not us,' he said. 'We love the church bells - we moved in to the house when the bells were on - but there is a difference between the bells and the chimes. We need to make that clear. We only said something about the chimes.' Nick Yates, spokesman for North Somerset council, said: 'Once we receive a complaint of a noise nuisance we have to investigate it.'

NACOGDOCHES RESIDENTS CAN FILE NOISE COMPLAINTS DIRECTLY WITH THE COURT

The City of Nacogdoches is taking the middleman out of filing process for noise violators. The action comes as the city continues to enhance enforcement of the city's noise ordinance. The new procedure allows private citizens to file charges directly with the Nacogdoches Municipal Court on persons violating the city's noise ordinance, according to the Nacogdoches Police Department. "Complainants must complete the application for complaint and the complaint itself, agree to testify in court, and sign both in person before a clerk of the Municipal Court," the Police Department said. "The complaint application has full instructions printed on it. On a fixed location, the actual address must be included", said Nacogdoches Police Chief Jim Sevey. "On a moving violation, such as a vehicle, a license plate number and description of the vehicle is needed at minimum." The noise complaints must be filed directly with the Municipal Court during their normal business hours. They cannot be taken at the police station or by police officers. Police officers will continue to enforce the noise ordinance. The citizen generated complaint process is designed to allow private citizens to take some action when officers are not present.