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Uncertainties in measurement of impact sound and consequences for conformity assessment

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Fulfilment of requirements in building codes can be documented by predictions and measurements. In the Norwegian “Regulations on technical requirements for construction works” (TEK17), this is given as a qualitative requirement: "Acoustic conditions shall be satisfactory for people inside construction works". Furthermore, it is stated that this qualitative requirement can be met by compliance with class C in Norwegian standard NS 8175: 2012. The regulations do not deal with uncertainty, neither in calculations nor measurements. The revised NS 8175:2019 states that the expected value from measurements is to be compared with the limit values, and at the same time that standard uncertainty with 90 % confidence level for two-sided test according to NS-EN ISO 12999-1 shall be reported, which can lead to confusion about the validity of the results, i.e. whether the corresponding limit value is exceeded or not. Based on general uncertainty and risk concepts (such as producers and consumers risk), and results from field measurements, some consequences of including uncertainty in conformity assessment are discussed, with emphasis on requirements for impact sound insulation.

1 Introduction

Requirements for acoustic conditions in buildings in Norway is qualitatively stated in “Regulations on technical requirements for construction works” (TEK17, [1]) as “[…] shall be satisfactory for people staying in buildings” based on intended use of the rooms or buildings. The purpose of the performance requirements is to “[…] ensure the possibility for work, rest, recreation, sleep, concentration […]”.

Several normal situations in buildings are described in the national classification standard NS 8175:2012 [2] with different sound condition descriptors with associated limit values in the different classes. For impact sound insulation in dwellings, the descriptor is normalised impact sound pressure level and the current criterion for fulfilment of the qualitatively described performance in TEK17 is $L'_{n,w} \leq 53$ dB (class C in NS 8175:2012).

The revised version of NS 8175: 2019 [3] introduces measurement uncertainty, but it is not clearly stated how this should be handled in conformity assessment. Some basic concepts regarding uncertainty and risk that can be helpful when discussing the consequences of measurement uncertainty are presented.

Uncertainties related to expanded frequency range down to 50 Hz (which applies to measurement of both reverberation time and sound level) is also of interest but is not addressed in this paper.

2 General uncertainty concepts

2.1 Accuracy and uncertainty

Terms and concepts regarding uncertainty in general can be found in ISO 5725-1:1994 “Accuracy (trueness and precision) of measurement methods and results. Part 1: General principles and definitions” [4] and JCGM 100:2008 “Evaluation of measurement data. Guide to the expression of uncertainty in measurement” [5].

In ISO 5725-1 “precision” refers to the closeness of agreement between test results and is normally expressed in terms of standard deviations. JCGM 100 defines “uncertainty (of measurement)” partly as a parameter that characterizes the dispersion of the values that could reasonably be attributed to the measurand, and may be a standard deviation or multiple of it, or an interval having a stated level of confidence (category A uncertainty – evaluated by statistical methods). According to these definitions, the terms “precision” and “uncertainty” can be characterized as random effects, describing the same aspect of measurements, and are in principle inversely proportional. Even though JCGM 100 states that there is not always a simple correspondence between classification of uncertainty into categories A or B (category B: uncertainty evaluated by other means than statistical methods) and previously used classification into “random” and “systematic” uncertainties, the terms “random” and “systematic” might be easier to understand. Uncertainty due to systematic effects can be described as an offset relative to a known or unknown “true” value (“trueness” in ISO 5725-1). A simple example is wrong calibration of the measuring system.

The combined uncertainty due to random and systematic effects in JCGM 100 is approximately equal to the term “accuracy” in ISO 5725-1. See Figure 1 for a schematic illustration of the different terms. The lower left quadrant of the figure represents negligible random and systematic effects, or high accuracy, and the upper right quadrant represents large systematic and random effects, or low accuracy.

The upper left quadrant may be characterized as problematic, as the dispersion of values is small and hence the result is seemingly accurate, but it is not representative for the “true” value of the measurand. The figure shows that uncertainty is not only related to the dispersion of values – systematic effects do affect the resulting uncertainty. An example related to field measurement is described in chapter 2.3.

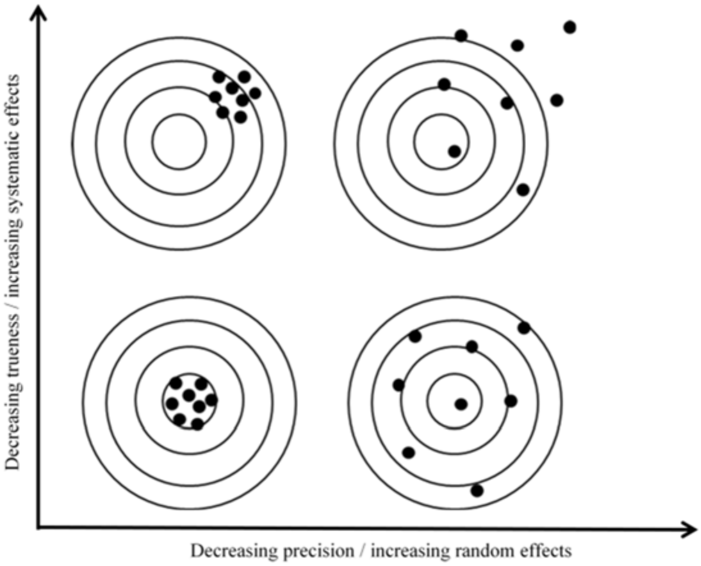

Figure 1: Illustration of accuracy and combined uncertainty related to the terms trueness/systematic effects and precision/random effects.

2.2 Uncertainty in building acoustics

Uncertainties in building acoustics measurements are defined in NS-EN ISO 12999-1:2014 “Acoustics. Determination and application of measurement uncertainties in building acoustics. Part 1: Sound insulation” [6]. The standard states the uncertainties of the impact sound measurement method. The inherent product scatter of usual building elements is not within the scope of the standard. Uncertainties are given as standard deviations for both single number quantities (SNQs, or descriptors, e.g. normalized impact sound pressure level, $L'_{n,w}$) and for 1/3-octave bands. Standard deviations are related to three different measurement situations with main characteristics as shown in Table 1.

Table 1: Main characteristics for different measurement situations according to NS-EN ISO 12999-1.

Measurement situations defined in NS-EN ISO 12999-1	Location		Object		Operator		Measuring system	
	Same	Other	Same	Similar	Same	Other	Same	Other
Reproducibility (situation A)		X	(X)	X		X		X
In situ (situation B)	X		X			X		X
Repeatability (situation C)	X		X		X		X	

In all measuring situations the measurements are carried out on the same or a similar object. Standard deviation (uncertainty) for "Reproducibility" conditions is expected to be larger than the standard deviation for "In situ" conditions, which in turn is expected to be larger than the standard deviation for "Repeatability" conditions.

2.3 Field measurement of impact sound – dispersion in data

In every step involving averaging, information is lost, and can hide outliers or general dispersion in the measurement data. Single number quantities (SNQs), like impact sound level $L'_{n,w}$, are typical examples of averaged data. In a special case, where 16 apartments where thoroughly measured to document the acoustic conditions, SNQs were not enough to assess the situation. The 16 apartments are arranged in a building complex of four houses with four apartments over three floors in each house. Each apartment comprises of several factory-made lightweight wooden structure modules. A schematic view of constructions and separating wall between two adjacent apartments is shown in Figure 2. Wooden joists in floor constructions are perpendicular to, and continuous under, the separating wall.

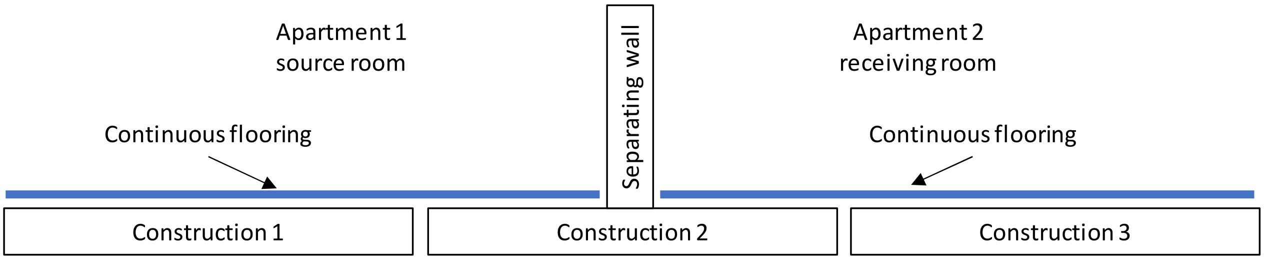

Figure 2: Schematic view of constructions and separating wall between two adjacent apartments.

Construction 1, 2 and 3 in Figure 2 are more or less separate, which means that the distribution of four tapping machine positions has a large effect on the measurement result, see example in Table 2: Energy average depending on number of positions on Construction 1 and 2.

Table 2: Energy average depending on number of positions on Construction 1 and 2.

	# positions on Construction 1	# positions on Construction 2	$L'_{n,w}$ (energy average)	Standard deviation
Result 1	4	0	38,2 dB	3,3 dB
Result 2	2	2	53,3 dB	2,7 dB
Result 3	0	4	55.7 dB	2,7 dB

The concepts of accuracy/uncertainty can be used to examine data for each individual measurement, i.e. the eight series of measured sound pressure level before averaging. The arithmetic mean of standard deviations in 1/3-octave bands for a total of 17 measurements of Result 1 and Result 2 constellations, and similar for a total of 24 measurements of Result 3 constellations, are shown in Figure 3.

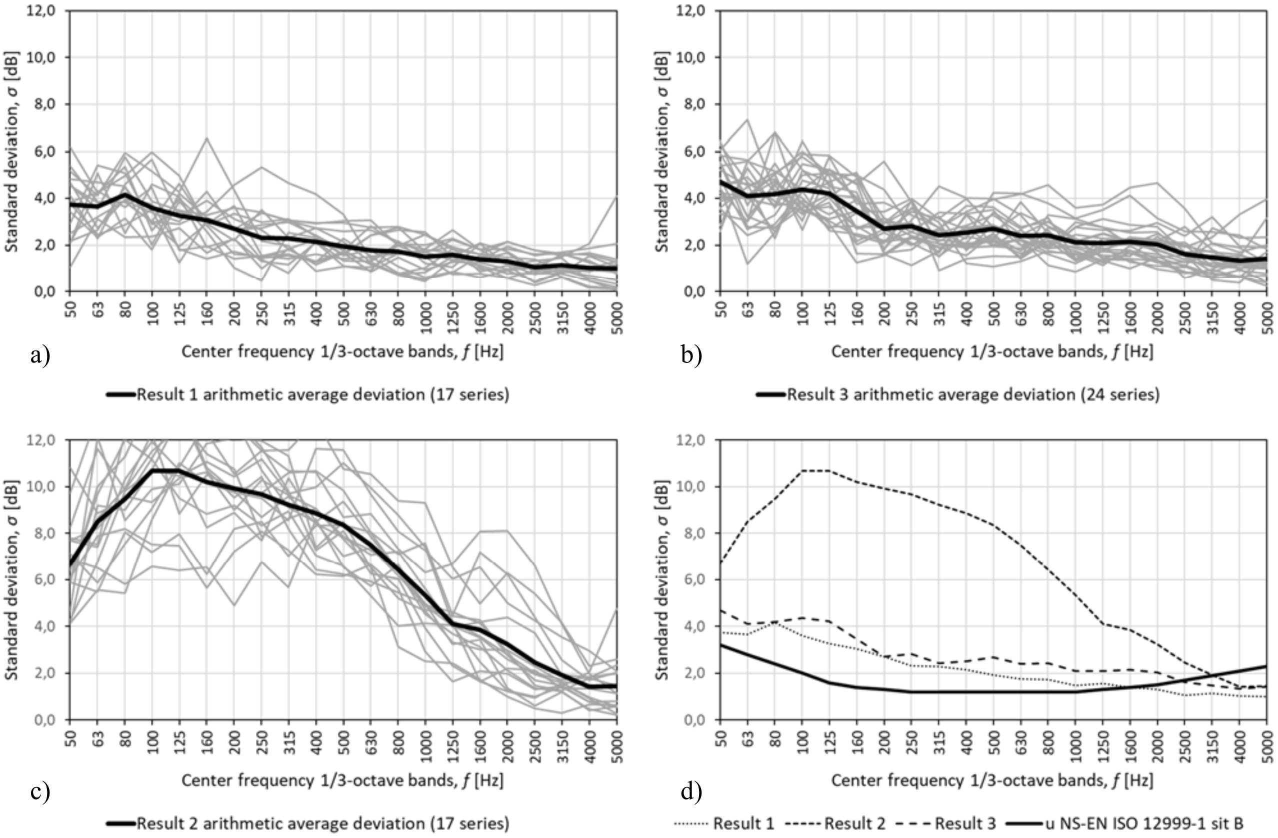

Figure 3: Arithmetic mean of standard deviations for three different series constellations of measured sound pressure level in the receiving room from the tapping machine (a, b and c) compared to the standard deviation for “In situ” conditions/situation B in NS-EN ISO 12999-1 (d).

Figure 3 c) shows large dispersion (low precision) in the sound pressure level measurement series. Information about this dispersion is lost after averaging, and can lead to systematic effects, or offset from the “true” value. In further data processing and assessment this means shifting the accuracy of the results from the upper (or lower) right quadrant in Figure 1 (large dispersion with or without deviation from “true” value”) to the upper left quadrant (apparently precise but with large deviation from “true” value of the measurand).

The averages shown in Figure 3 a) and b) are larger than the NS-EN ISO 12999-1 standard uncertainty for “In situ” conditions, except for 1/3-octave bands f = 2.5kHz-5.0kHz (Figure 3 d). An expanded uncertainty with coverage factor k = 1.96 encompasses most of the 1/3-octave band values. This is probably partly due to the spatial distribution of receiver points, as levels near the separating wall was generally higher than in more remote parts of the receiving volume.

3 General risk and acceptance concepts

The major steps in risk assessment according to the Norwegian national standard NS 5814:2008 “Requirements for risk assessment” [7] are shown in Figure 4. Especially “Establish risk acceptance criteria” is of concern when it comes to conformity assessment using measurement results to document whether requirements are met or not.

Figure 4: Major steps in risk assessment and management according to NS 5814:2008.

Acceptance criteria are addressed in JCGM 106:2012 "Evaluation of measurement data – The role of measurement uncertainty in conformity assessment" [8]. An example of a decision rule based on simple acceptance near an upper tolerance limit is shown in Figure 5 (adapted from JCGM 106, Figure 8). The rule is also called shared risk and implies in this case that an item is accepted as conforming when the measured value is lower than the tolerance limit (T_U). The figure also shows the risk of incorrect decisions; "False acceptance" and "False rejection". False acceptance means that there is a probability that non-conforming items are accepted, also called consumers risk, and false rejection that there is a probability of rejecting conforming items, also called producers risk.

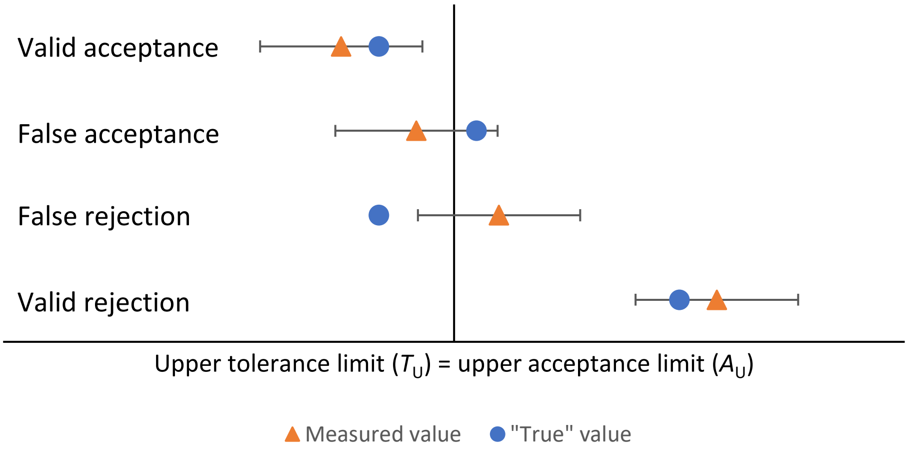

Figure 5: Four possible outcomes given the value from a single measurement combined with coverage interval chosen according to the uncertainties of the measurement method (adapted from JCGM 106, Figure 8).

4 Uncertainty and risk as part of impact sound conformity assessment

4.1 Impact sound requirements and implicit acceptance rule

Most situations in NS 8175 are defined by an acoustical descriptor combined with a one-sided tolerance interval and a given upper limit (the exceptions being sound reduction index, R'_w, and absorption coefficient, α, which have lower limits). Descriptor and limit value for impact sound in dwellings are shown in Table 3. TEK17 is still referring to NS 8175:2012. Consequences by introducing the 2019-version have not been fully assessed by the building authorities yet. When it comes to measurement uncertainty, conformity assessment is not really clarified in the new version.

Table 3: Descriptors and limit values in NS 8175:2012 and NS 8175:2019 and descriptions on how measurement uncertainty should be handled.

	Descriptor	Limit value	On measurement uncertainty (translated from Norwegian)
NS 8175:2012	$L'_{n,w}$	≤ 53 dB	Unless otherwise stated, the measurement result (expected value) shall be compared with the limit value. The uncertainty in the measurement results should be handled as given in the relevant regulations and legislation.
NS 8175:2019	$L'_{n,w} + C_{I50,2500}$	≤ 54 dB	The measurement result (expected value) shall be compared with the limit value. Two-sided standard measurement uncertainty with 90 % confidence level shall be reported for airborne and impact sound measurements. The uncertainty in the measurement results should be handled as given in the relevant regulations and legislation.

The current design of limit values and measurement uncertainty in both versions of NS 8175 are implicitly applying the simple acceptance rule (see Figure 3), where the consumer/producer risk (and cost) is shared 50/50. Including measurement uncertainty in measurement reports without implementing uncertainty in the conformity assessment can be confusing and raise questions about the validity of the results.

4.2 Acceptance rule based on guard bands

One implication of the simple acceptance rule is that close to the tolerance/acceptance limit the probability of a wrong decision (acceptance/rejection) can be as large as 50 % when based on only one measurement. To reduce this risk of wrong decisions, guard bands could be introduced around the upper tolerance limit (as is the case for impact sound requirements), see Figure 6.

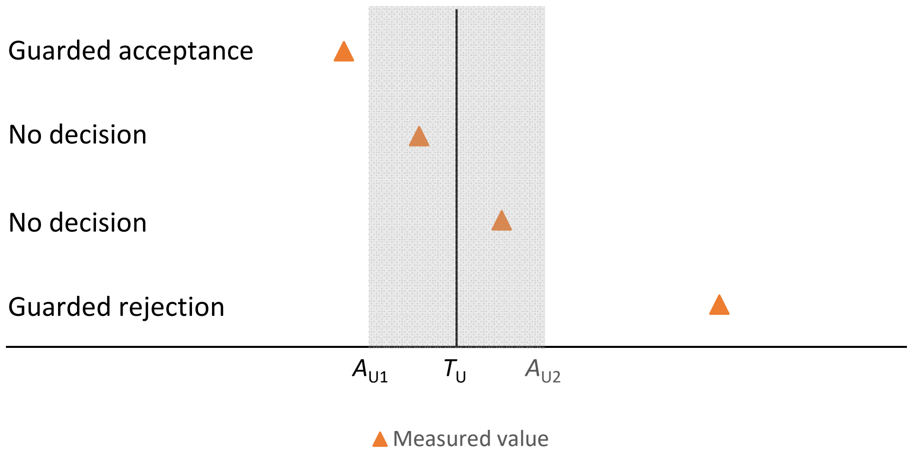

Figure 6: Acceptance rules based on guard bands.

Decision rules are closely related to risks (and associated costs) for the individual customer and the producer. Conformity assessment should preferably be explicitly designed including these aspects.

If both consumer and producer risk are to be included, two acceptance limits are needed, A_{U1} and A_{U2} respectively. The acceptance limits can be set to different values/intervals, depending on how consumer and producer risks are weighted against each other. The result is a region between the acceptance limits where no decision can be made by measurements alone, although more measurements could be carried out to reduce the uncertainty. If the item to be measured for a second time has not been altered and the room conditions are the same (location and object in Table 1), the same person using the same measuring system, measurement conditions are equivalent to “Reproducibility”, which also has lower standard uncertainties than the first “In situ” measurement. With acceptance limits connected to the level of uncertainty, this could reduce the “No decision” region. Regardless of the number of consecutive measurements, there will still be a set of values close to the tolerance limit where the decision to accept or reject has to be handled by other means than measurements.

Which coverage factor (k) to be used to calculate expanded uncertainty is also of importance. To encompass most of the 1/3-octave band uncertainties from measurements shown in Figure 3 a) and b), a coverage factor of approximately 1.96 is needed when applying “In situ” conditions. It should be mentioned that this is a rather special case, but it might be feasible to consider different coverage factors for different constructions (lightweight/heavy) and measurement direction (horizontal/vertical).

References

[1] Kommunal- og moderniseringsdepartementet, ‘FOR-2017-06-19-840 Forskrift om tekniske krav til byggverk (Byggteknisk forskrift - TEK17), sist endret FOR-2020-03-03-242’, Oslo, Jul. 2017. [Online]. Available: https://lovdata.no/dokument/SF/forskrift/2017-06-19-840.

[2] Standard Norge, ‘NS 8175 Lydforhold i bygninger. Lydklasser for ulike bygningstyper’, 2012.

[3] Standard Norge, ‘NS 8175 Lydforhold i bygninger. Lydklasser for ulike bygningstyper’, 2019.

[4] ISO, ‘ISO 5725-1 Accuracy (trueness and precision) of measurement methods and results - Part 1: General principles and definitions’, Dec. 1994.

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[8] JCGM, ‘Evaluation of measurement data - The role of measurement uncertainty in conformity assessment’, Joint Committee for Guides in Metrology, JCGM 106, 2012.