

ISO/TS 19488 AND THE NEEDED NUMBER OF MEASUREMENTS TO VALIDATE A CLASS

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The standard ISO/TS 19488 considers, that, when verifying the acoustic class of a unit, a sufficient number of measurements of each relevant acoustic characteristic must be performed in order for the result to represent the unit. The number of measurements may be reduced, when the verification includes comparisons to similar constructions or theoretical calculations or as a combination thereof. The question now arises: what number of measurements is sufficient to represent the unit, i.e. validate the acoustic class of a unit? ISO/TS 19488 specifies percentages in the current version and also the sampling procedure, which is currently under discussion, focuses on how to select the number of tests that are necessary to validate the classification. Currently ISO/TS 19488 describes two procedures: Procedure A with a 5% and B with a 10% of the structures tested.

In this article, the necessary number of minimum measurements to be carried out using statistical theory is given if a certain confidence of the results is to be given.

Keywords: classification, statistics, airborne sound insulation

1. Introduction

ISO/TS 19488: Acoustics - Acoustic classification of dwellings [1] describes criteria and procedures for acoustic classification of dwellings. The purpose of ISO/TS 19488 is to specify a classified level of acoustic quality for a dwelling. The standard can be applied as a tool to characterize the quality of the existing housing stock and includes provisions for classifying the acoustic quality before and after renovation has taken place. The classification of a dwelling or a residential building according to ISO/TS 19488 is based on a verification procedure described therein. Two alternative verification procedures are described, namely: Procedure A with 5 % of the structures and rooms to be measured with a safety margin of at least 2 dB, and Procedure B, in which at least 10 % of the types of construction of separating walls and floors must be measured in such a way that they are sufficiently representative of the unit with an uncertainty of 2 dB. When verifying the acoustic class of a unit, the general principle is that a sufficient number of rooms should be selected in order for the result to represent the unit and each relevant acoustic characteristic should be evaluated for this unit. However, the minimum number of measurements for each structure type and acoustic characteristic is always 3. Procedure A describes the design stage of a building. The performance of the constructions can be estimated by theoretical calculations. Procedure B describes the verification by field measurements only. The verification shall be based on a number of measurements to characterize each aspect of the acoustic classes in the completed building or unit. The question arises as to how many measurements are necessary if a reliable statement is to be made that a

certain limit value, e.g. the required sound insulation value, is complied with for the total number of components to be tested. This question can be answered with the help of inferential statistics, based on a sample. Inferential statistics is a subset of statistics that is used to infer a larger population from a sample. The aim of a random sample is to approximate the distributions of properties (here: sound insulation) in the population (here: the building). Basically, a statement about a sample can only ever be valid for the sample itself with one hundred percent certainty, the approximate validity for the population is made by statistically derived. Since the aim of a sampling method is to examine as small a subset as possible, statistically very high demands are placed on the sample. In order to ensure the representativeness of the sample for the population, the necessary sample size must be statistically calculated [2], and the appropriate type of sample must be determined by organisational checks. In practice it is first necessary to determine the desired accuracy of the survey. Furthermore, the standard deviation must be calculated, for which the assumed maximum and minimum sound insulation is used. For reasons of practicability, a tolerant quality requirement can also be selected and thus the effort of the scope of measurement can be significantly reduced. This paper calculates the minimum necessary measurement scope (number of measurements) to ensure the selected quality requirement and describes the corresponding dependencies of the number of measurements (sample size) on the selected confidence level (confidence level), the expected defect rate (error rate) and the accuracy of the sample estimate (margin of error) [3-6]. Calculation examples are used to show how many separating components in apartments of large buildings have to be measured so that the result is representative of the entire building (e.g. 30 apartments) at a selected level of confidence (e.g. 95%).

2. Statistical Framework

The sample size calculation is based on classical statistical sampling theory for finite populations. The approach assumes a conservative estimate of the proportion of non-compliant units and incorporates both statistical uncertainty and measurement uncertainty. The calculation is based on the estimation of a proportion of defective components (too little sound insulation compared to the required value) within a finite population (buildings with N apartments or partition walls). It is assumed that a small proportion of the apartments (here: partition walls) could fail the requirement. In other words, the required sound insulation fails the target value during the metrological inspection, i.e. the measured sound insulation is less than the target value.

Following assumptions are made:

- Random selection of components to be measured (apartments)
- Homogeneous construction of the components (partition walls).
- Independent measurement results.
- Population normally distributed.

3. Parameters used

Parameter	Meaning	Value
p	assumed proportion of non-compliance (conservative assumption)	variable
E_{stat}	statistical margin of error	variable
E_{eff}	effective margin of error	variable
Z (95 %)	standard normal value corresponding to the confidence level for 95%	1,96
m	measurement uncertainty	variable
$R'_{w,\text{req.}}$	required sound insulation (target value)	53 dB
N	number of components	variable

3.1 Assumed proportion of non-compliance p

To illustrate the assumed proportion of non-compliance p , i.e. the assumed proportion of non-conforming components, the meaning of p for $N = 30$ is described below in relation to the situation.

Situation	Meaning of p	Expectation
It is assumed that almost all components are ok	$p = 5\%$	approx. 1-2 components out of 30 possibly faulty
A few could be faulty	$p = 10\%$	about 3 out of 30 possibly faulty
It is completely unclear how many or how few are defective (worst case)	$p = 50\%$	half of the components may be faulty

3.2 Determination of the statistical margin of error E_{stat}

The margin of error quantifies the uncertainty of the measured results. So, the margin of error is a component of the confidence interval that specifies the width of the confidence interval. That is, the margin of error indicates the maximum and minimum of the accepted values of the quantity under consideration. A larger sample size usually results in a smaller margin of error, indicating more precise results. This means that a smaller margin of error indicates that the measurement result is closer to the true value, while a larger margin of error indicates greater uncertainty and a wider range of possible results. The acceptable margin of error at 95% confidence level is around 5% [3]. The statistical margin of error is calculated according to equation (1):

$$E_{\text{stat}} = Z \left(\frac{s}{\sqrt{n}} \right) \quad (1)$$

s stands for the standard deviation, n for the sample size, and Z for the Z -value (taken from the Z table). The equation shows the inverse relationship between sample size and margin of error. E_{stat} is usually given or assumed (estimated) to estimate the sample size.

3.3 Determination of the Z -value

The Z -value corresponds to the desired confidence probability (confidence level) and indicates how far a data point is from the mean in standard deviation units. A confidence level of 95% corresponds to a Z -value of 1.96, while a confidence level of 99% is associated with a Z -value of 2.58. Table 1 shows the most common values.

Table 1: Standard normal distribution (Z -values), from [7]:

Confidence probability	Z -value
80%	1,28
85%	1,44
90%	1,65
95%	1,96
99%	2,58

3.4 Consideration of the measurement uncertainty

The measurement uncertainty is considered as an additional uncertainty component and related to the "target value" [4]:

$$E_{err} = \frac{\text{Measurement uncertainty}}{\text{Requirement}} = \frac{m}{R'_{w,req.}} \quad (2)$$

The effective margin of error is then:

$$E_{eff} = E_{stat} + E_{err} \quad (3)$$

The effective margin of error (E_{eff}) consists of the statistical margin of error and the relative measurement uncertainty. This ensures that both the statistical dispersion and the metrological uncertainty are conservatively covered.

4. Sample size calculation

4.1 Uncorrected sample (large population)

The derivation of the sample size formula is described in [3]. The size of the sample is calculated according to equation (4) under the assumption of a normal distribution.

$$n_0 = \frac{Z^2 p (1-p)}{E_{eff}^2} \quad (4)$$

4.2 Correction for finite population (FPC)

Since the number of dwellings is limited, the sample size is adjusted using the finite population correction. The correction for "finite" quantities (small population) is done by the "finite population correction (FPC) [8]". The corrected sample size for small N is then calculated as:

$$n = \frac{N n_0}{n_0 + (N-1)} \quad (5)$$

4.3 Final number of measurements

The final required number of measurements is obtained by rounding up: $n_{final} = \lceil n \rceil$
(round up to the nearest whole number)

5. Example

As an example, a confidence interval of 95% with an estimated proportion of 50% (worst case) of components that do not meet the requirements is assumed. The absolute margin of error (E_{stat}) is varied and is: 1%, 10% and 20%. In this calculation, p stands for the expected proportion (percentage) of components (or apartments) for which the sound insulation coefficient will not meet the required performance of e.g. $R'_w = 53$ dB according to DIN 4109 [9] for apartment partition walls, i.e. the proportion of non-compliant components in the entire sample. In other words, p is equal to the probability that a randomly selected component will be non-compliant. A concrete result for the "worst case" with $p = 50\%$ and a selected confidence range of 95% shows that with a margin of error of $E_{stat} = 1\%$ for a total of 30 components, 30 components must be checked. With a margin of error of 10%, there are still 24 components and with a 20% margin of error, 14 components still have to be checked. Figure 1 shows this situation graphically.

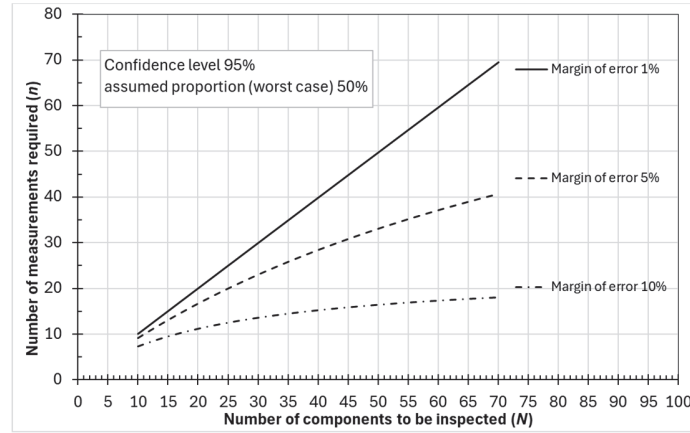


Figure 1: Required number of measurements (minimum sample size n) as a function of the population N (number of components) for different margins of error (E_{stat}), without a measurement uncertainty (m).

Figure 1 shows the proportion of components that need to be tested, i.e. the number of measurements required, depending on the number of components (population of components) with different statistical margins of error (accuracy of the sample estimate) and an assumed proportion of non-conforming components of 50% (worst case). It turns out that as the margin of error grows, fewer measurements are needed. If a measurement error (m) is added to the statistical margin of error (E_{stat}), the effective margin of error (E_{eff}) is obtained according to equation (3). For comparison: With a target value of 53 dB and a measurement uncertainty of ± 2 dB ($E_{\text{err}} \approx 3.77\%$) and a statistical margin of error of 10%, the effective margin of error is $E_{\text{eff}} = 13.8\%$ (rounded up 14%). So instead of a 10% margin of error, there is effectively 14%, which means that the required sample size decreases, i.e. becomes smaller. If the margin of error E is varied and the proportion of non-conforming components, e.g. $p = 1\%$ is kept constant, the sample sizes shown graphically in Fig. 2 are obtained.

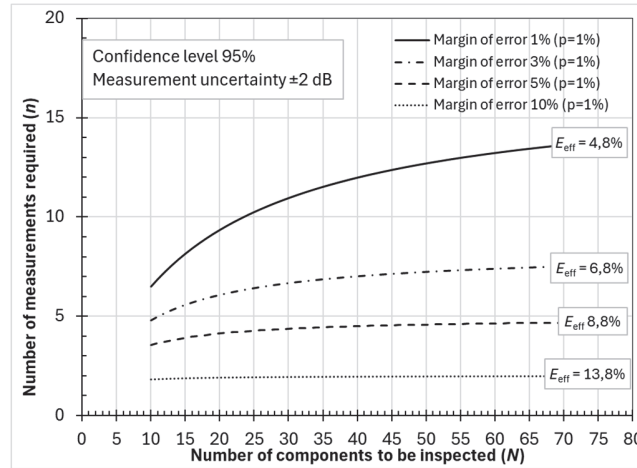


Figure 2: Influence of the margin of error E_{stat} on the sample size n at a constant assumed proportion p of 1% considering a measurement uncertainty of ± 2 dB.

The example ($N = 30$ and 95% confidence) shows exemplary the facts in Fig. 2 numerically:

$p = 1\%$:	$E_{\text{stat}} \pm 1\%$	$\rightarrow$	$n \approx 11$
$p = 1\%$:	$E_{\text{stat}} \pm 3\%$	$\rightarrow$	$n \approx 7$
$p = 1\%$:	$E_{\text{stat}} \pm 5\%$	$\rightarrow$	$n \approx 5$
$p = 1\%$:	$E_{\text{stat}} \pm 10\%$	$\rightarrow$	$n \approx 2$

In the next Fig. 3 the influence of the statistical margin of error E_{stat} on the sample size n for an assumed proportion of non-conforming components $p = 50\%$ (worst case) without considering a measurement uncertainty is shown.

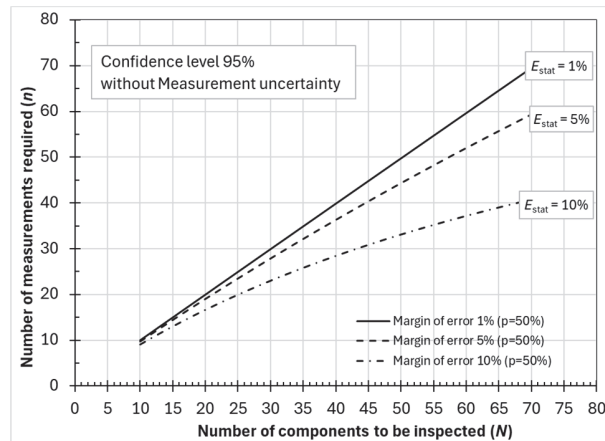


Figure 3: Influence of the margin of error E_{stat} on the sample size n at an assumed proportion $p = 50\%$ (worst case) without considering a measurement uncertainty.

In Fig. 3, the comparison of the graphs shows that the sample size increases sharply with small margins of uncertainty. With a very small margin of error (1-3%), the functional relationship is almost linear in the "worst case", so that a reduction in the measurement effort is not worthwhile or is very low. If, on the other hand, an error margin of 10% is tolerated, a considerable number can be saved with a large number of components to be tested. In practice, however, a measurement uncertainty is always to be expected, so that the measurement error must be added to the margin of error to be considered. Figure 4 considers a measurement uncertainty of ± 2 .

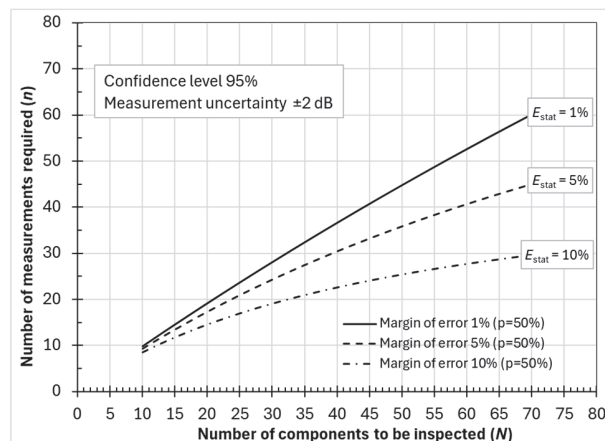


Figure 4: Influence of the margin of error E_{stat} on the sample size n at an assumed proportion $p = 50\%$ (worst case) with consideration of a measurement uncertainty of ± 2 dB.

The comparison of Fig. 3 and Fig. 4 shows that the sample size is significantly reduced. For the "worst case" and $N = 30$, the following sample sizes (n) result with and without measurement uncertainty:

without measurement uncertainty (E_{stat})		with measurement uncertainty (E_{eff})	
$E_{\text{stat}} = 1\%$:	$\rightarrow n \approx 30$	$E_{\text{eff}} \pm 1\%$	$\rightarrow n \approx 29$
$E_{\text{stat}} = 5\%$:	$\rightarrow n \approx 28$	$E_{\text{eff}} \pm 5\%$	$\rightarrow n \approx 25$
$E_{\text{stat}} = 10\%$:	$\rightarrow n \approx 24$	$E_{\text{eff}} \pm 10\%$	$\rightarrow n \approx 20$

The influence of the measurement uncertainty on the minimum sample size for $N = 10$ to 70 is shown in Fig. 5. For large buildings ($N > 30$), the required sample size n is significantly smaller than without a measurement uncertainty because of the measurement uncertainty.

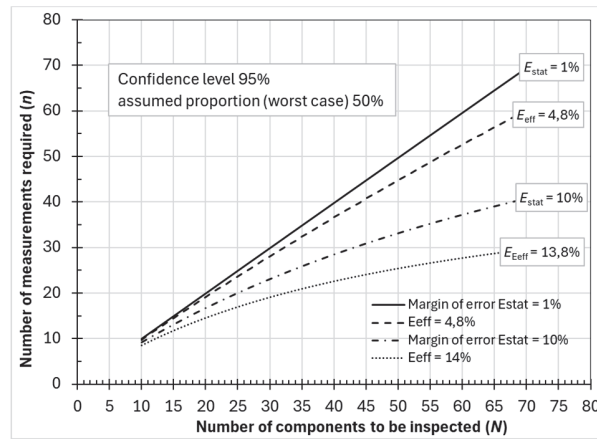


Figure 5: Influence of the measurement uncertainty ± 2 dB on the sample size n for an assumed proportion $p = 50\%$ (worst case) with a margin of error of $E_{stat} = 1\%$ and $E_{stat} = 10\%$.

The number of sample sizes n as shown in Fig. 5 is significantly reduced by including the measurement uncertainty. The greater the statistical margin of error (E_{stat}), the greater the impact. It turns out that with increasing measurement uncertainty; fewer measurements are needed. For larger buildings, the results show that the required minimum number of measurements approaches a limit value (saturation) [7]. In the case of small measurement uncertainty, the sample size increases sharply. This factual situation results from Fig. 6. In this graph, the sample size is considered with a margin of error of 1% and 10% once with and without measurement uncertainty of 1 dB, 2 dB and 3 dB.

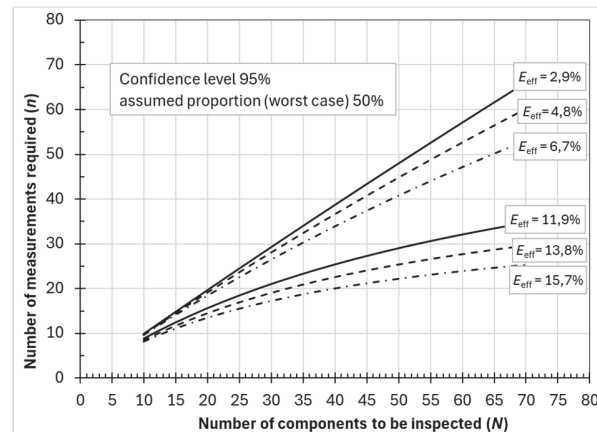


Figure 6: Influence of measurement uncertainty ± 1 dB, ± 2 dB, ± 3 dB on the sample size n at $E_{stat} = 1\%$ and 10% for an assumed proportion $p = 50\%$ (worst case).

Note on the interpretation of these figures:

Mathematically, a larger measurement uncertainty results in a larger $E_{eff} = E_{stat} + E_{err}$. Because a larger effective margin of error is accepted, the result may be a smaller sample, but this does not mean that the test statement will be better. On the contrary: a greater measurement uncertainty makes the measurement less precise in dB terms. The smaller n at ± 3 dB only means that the same statistical "margin of error" is achieved with a coarser (less sharply defined) measurement requirement. For large buildings ($N > 30$), the sample size is significantly reduced with a lower confidence level.

6. Conclusion

The required number of measurements does not increase linearly with the size of the building. From medium building sizes, the additional measurement effort increases only slightly. However, in the case of a small population (few apartments), it often does not make sense to limit the measurement effort and to estimate the totality by means of a random sample. Nonetheless, if the population is large (a large number of dwellings), it may make sense to limit the scope of the measurement and to sufficiently reduce the measurement effort through careful sampling planning. The higher the desired accuracy, the larger the sample size must be. The confidence level is usually given as 95%; statistically, it results from the normal distribution. Charts provide a compact, visual summary of sampling planning and enable:

- a quick estimation of the measurement effort,
- a comprehensible justification of the selected sample size.

In summary, it can be stated that the needed number of measurements cannot be given as a general rule if a particular statistical certainty is to be sought. This means that a 5% or 10% sample size cannot be specified for any number of components to be measured. The present study on sampling planning has shown that the minimum number of measurements of 3 as specified in ISO/TS 19488 has a very low statistical certainty. In order to ensure statistical certainty with an arbitrary sample, the minimum number of measurements to be carried out must be individually adapted to the actual situation. A chart in the ISO/TS 19488 standard or the individual calculation of the necessary sample size could help to determine the necessary sample size with a stated statistical certainty.

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