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Rindel, Jens Holger; Rasmussen, Birgit

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Some consequences of including low frequencies in the evaluation of floor impact sound.

Jens Holger Rindel and Birgit Rasmussen[1]
Department of Acoustic Technology,
Technical University of Denmark, Building 352,
DK-2800 Lyngby, Denmark

ABSTRACT

A method for including frequencies down to 50 Hz in the evaluation of floor impact sound has become available with the new version of ISO 717-2. In addition to the single number quantity for rating of the impact sound insulation, a new spectrum adaptation term has been defined. The method has been studied by the Acoustics Group of NKB (Nordic Committee on Building Regulations). The new method has been applied to a large number of recent measuring results from the Nordic countries. It was found that the spectrum adaptation term for the extended frequency range depends on the type of floor construction, and light floor constructions are evaluated less favourable than heavy constructions. Comparison with data from a 14 years old Swedish survey suggests that the extended frequency range leads to a higher correlation with subjective evaluation of impact noise. The consequences of applying the extended frequency range in future building regulations or in a system for acoustic classification of dwellings has been considered. However, there are several problems to be solved, among which are a lack of available data for floor constructions at low frequencies, an increased measurement uncertainty, and some floor constructions are evaluated too favourably by the new method

INTRODUCTION

Until now the international building acoustic rating methods ISO 717 have been based on measurement results covering the frequency range 100-3150 Hz corresponding to the measurement methods in ISO 140. The acoustic requirements in most European countries refer to the methods in ISO 717 or similar national methods, even if concepts and details vary considerably between countries. In the Nordic countries the present airborne and impact sound insulation requirements for buildings are expressed as minimum R'_w and maximum $L'_{n,w}$ values.

[1]Present address: VELUX A/S, Maskinvej 4, DK-2860 Søborg, Denmark

The revised standards for rating of airborne and impact sound insulation, among other things, open up the possibility to apply spectrum adaptation terms for the above-mentioned frequency range 100-3150 Hz or for an extended frequency range by adding the relevant C-corrections defined in the new ISO 717, when specifying sound insulation results and requirements Especially, an extension of the frequency range towards lower frequencies does imply significant consequences The use of C-corrections for an extended frequency range is of course dependent on the ISO 140 series, which is also under revision.

An growing need to include the low frequencies in the legal requirements has been recognized Low frequency problems may be increasing due to a building construction trend towards more light-weight constructions allowing a stronger low frequency transmission of some types of structure borne noise, eg footfalls. Unless the low frequencies get included in the legal requirements, the optimization might continue to focus on the traditional frequency range, implying a big risk for future buildings with acoustic quality of the past

As shown by Blazier & DuPree (1994) the low frequency problems related to light-weight floor constructions can include frequencies as low as 20-25 Hz. However, in the present paper the extension of the frequency range down to 50 Hz is considered The reason for this is, that only this extension is included in the upcoming new international standards for measurement and evaluation of sound insulation.

The Acoustics Group of the Nordic Committee on Building Regulations (NKB) wanted to investigate the C-corrections for different types of building components/constructions and the possible positive implications to the correlation between the objective and subjective evaluation of sound insulation, cf Hagberg (1996) Another project was aimed at gathering information from other contries about future applications of the methods in the new ISO 717, cf Rasmussen (1996). In addition, the NKB Acoustics Group has prepared a draft proposal for a joint Nordic system for acoustic classification of dwellings, which might include use of C-corrections, where appropriate. This work has now been transferred to an INSTA B Committee (INSTA B is a cooperation between the organizations for building standardization in the five Nordic countries) This committee and the NKB Acoustics Group are chaired by the first author of this paper, and in the following some of the findings from this work will be displayed. The main characteristics of the European systems/proposals for acoustic classification of dwellings, including the use of the new spectrum adaptation terms, are described by Rasmussen (1996)

MAIN CHANGES IN THE UPCOMING ISO RATING METHOD FOR IMPACT NOISE

The ISO 717-2 rating method for impact sound is being revised thoroughly. The most significant change is the introduction of the spectrum adaptation term C_i The spectrum adaptation term may be calculated for the usual frequency range 100 - 3150 Hz or for an enlarged frequency range including the 1/3 octave frequency bands 50 + 63 + 80 Hz and/or 4000 + 5000 Hz Another piece of news is that 1/1 octave measurement results may be used instead of 1/3 octave measurement for rating of field measurements. The C-correction is equipped with an index specifying the frequency range, if enlarged The spectrum adaptation term for impact sound insulation is described in more detail in Appendix A

For the statement of test results on result sheets, the main result is to be stated as the single-number quantity in the usual way, and one or more C-corrections may be stated in brackets behind the main result. Requirements may be specified using solely a single-number quantity or be based on the sum of a single-number quantity and a spectrum adaptation term. Examples on statement of performance and requirements according to ISO/DIS 717-2 are shown below.

Examples on statement of performance in buildings:

$$L'_{n,w}\ (C_i;\ C_{i,50\text{-}2500}) = 48\ (1;\ 3)\ \text{dB}$$

Examples on statement of requirements:

$$L'_{n,w} \leq 50\ \text{dB}; \quad L'_{n,w} + C_i \leq 50\ \text{dB}; \quad L'_{n,w} + C_{i,50\text{-}2500} \leq 50\ \text{dB}$$

THE LOW-FREQUENCY PERFORMANCE OF DIFFERENT BUILDING CONSTRUCTIONS

One project of the NKB Acoustic Group was to investigate the behaviour of the new spectrum adaptation terms introduced in ISO/DIS 717-2. Measurement results in the extended frequency range down to 50 Hz were collected from the nordic countries. The measuring results are from field measurements made on typical building constructions, and the data are collected and published by Hagberg (1996). In his report Hagberg made the conclusion, that by a very rough averaging in two groups of construction the results were average $C_{i,50\text{-}2500}$ = -3 dB for heavy constructions (concrete etc.) and average $C_{i,50\text{-}2500}$ = +3 dB for light-weight constructions (wood etc.).

However, it is also possible to divide the constructions into three groups with somewhat smaller variation within each group, The result of this analysis is seen in Table 1. Only results from vertical transmission are used.

Type of construction	Number of measurements	$C_{i,50\text{-}2500}$ Average	Min	Max
Heavy	27	-3.2 dB	-11 dB	1 dB
Medium	53	1.5 dB	-2 dB	5 dB
Light	62	2.4 dB	-2 dB	13 dB

Table 1. Values of the low frequency spectrum adaptation term for impact noise as found in field measurements from the nordic countries. Based on data collected by Hagberg (1996).

Heavy constructions include concrete and hollow concrete. Medium-weight constructions are leca, EW-slab (combination of concrete and wood), and some other constructions. Light-weight constructions include wood, hardboard, gypsum and porous concrete. The results show a difference of around 6 dB between the average values in the heavy and light categories. However, the total spread is from -11 dB to +13 dB.

From this it is clear, that if the C-correction in the extended frequency range is taken into use, it will be more difficult for light-weight constructions to fulfil a certain impact sound requirement, whereas heavy constructions would be evaluated more optimistic In fact it could be claimed that a negative value of the C-correction should not be used, as this will typically appear in case of a hard floor surface, which gives footfall noise in the high frequency range. So, if negative C-corrections are allowed, there is a great risk to introduce high frequency problems for heavy constructions with hard floor coverings

CORRELATION BETWEEN OBJECTIVE AND SUBJECTIVE EVALUATION OF IMPACT NOISE

Bodlund (1985) measured impact sound level from 50 Hz to 5000 Hz in 22 new houses in Sweden A total of 211 measurements were made. In the same project the people living in the houses were questioned about the acoustic conditions including annoyance from footfall noise. A number of objective measures of impact sound insulation were investigated, and the correlation with subjective evaluation is shown in Table 2

Impact sound measure	I_i	L'_{nw}	L'_{nA}	L'_{nC}	L_B
Correlation with subjective evaluation	73%	75%	72%	85%	87%

Table 2. Correlation between objective and subjective evaluation of impact noise in 22 different houses. After Bodlund (1985).

In Table 2 I_i refers to ISO/R 717 (1968) - a forerunner of the present ISO 717 series and L'_{nw} refers to the present ISO 717-2 L'_{nA} and L'_{nC} are evaluated with the ordinary A- and C-weighting filters. The best correlation was obtained with a special evaluation method, L_B proposed by Bodlund (1985). The method is similar to the ISO 717 method, except that the reference curve is different, see Fig 1 The L_B value is based on the frequency range 50-1000 Hz, and the low frequencies are emphasized compared to the higher frequencies

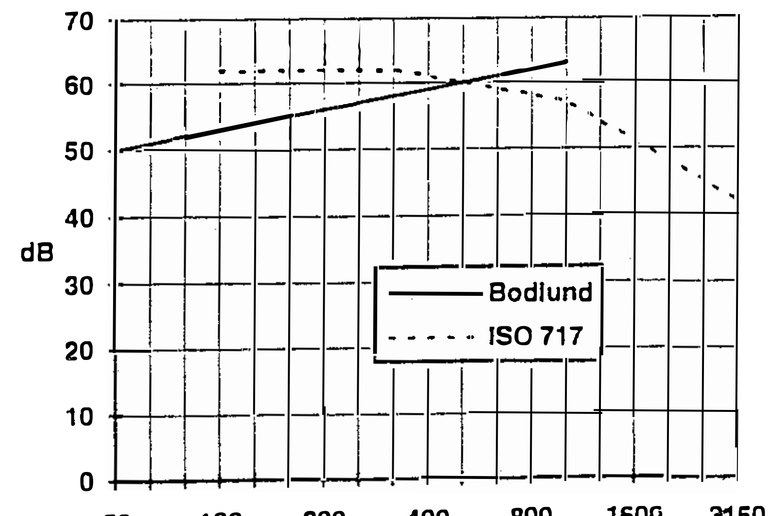

Figure 1. Reference curves for L_B after Bodlund (1985) and L'_{nw} after ISO 717-2

Unfortunately, the original data the 211 measurements in Bodlund's project were not available for a new analysis, in which the new evaluation methods could be studied. Instead a new collection of in total 146 measuring results from the nordic countries were analyzed, and the L_B value was calculated as well as the L'_{nw} and the new C-corrections C_i (normal frequency range) and $C_{i,50\text{-}2500}$ (extended frequency range)

If a measure of impact sound has a high correlation with the L_B -measure, it is assumed that the measure will also have a high correlation with subjective evaluation. The results of this analysis are shown in Table 3.

Impact sound measure	L'_{nw}	$L'_{nw} + C_i$	$L'_{nw} + C_{i,50\text{-}2500}$
Correlation with L_B	76%	90%	96%

Table 3. Correlation of the new ISO 717-2 measures of impact sound insulation with the L_B-measure. Based on field measurements of 146 floor constructions. After Hagberg (1996).

From the results in Table 3 it is concluded that the L'_{nw} has only a weak correlation with L_B whereas the inclusion of the low frequencies by adding the correction $C_{i,50\text{-}2500}$ improves the correlation significantly, namely from 76% to 96%. See also Fig 2 and 3.

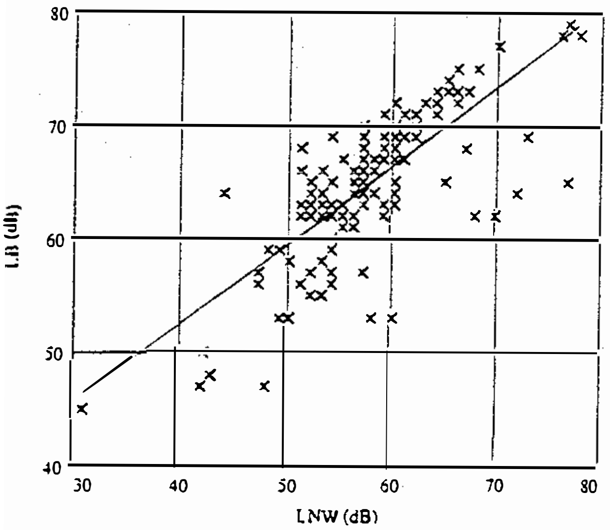

Figure 2. Correlation between L_B and L'_{nw}, $r = 76\%$. After Hagberg (1996).

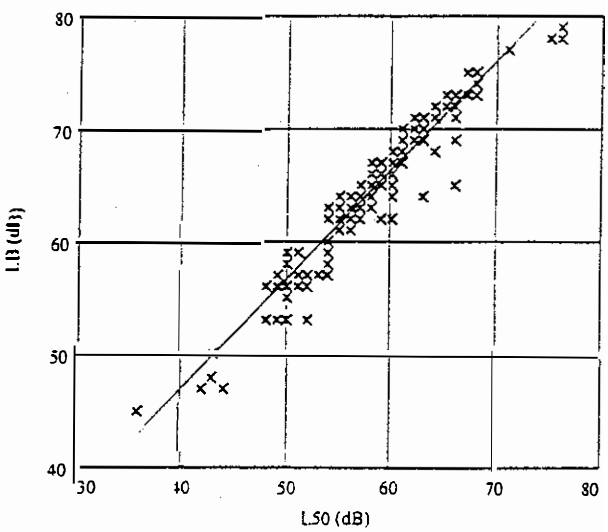

Figure 3. Correlation between L_B and $L'_{nw} + C_{i,50\text{-}2500}$, $r = 96\%$. After Hagberg (1996).

OBSTACLES TO IMPLEMENTATION OF THE LOW-FREQUENCY SPECTRUM ADAPTATION TERMS

Low frequencies will be included – for voluntary use – in the new measurement and rating methods in ISO 140 and ISO 717. For the present, the ISO 140 test methods remain insufficient regarding precision at low frequencies. Low-frequency considerations are also included in NT ACOU 084 (1992), which forms the basis for a new ISO work item proposal, including intensity measurements in the field

However, even in case that someone decided to try out the full possibilities of the upcoming ISO 717, ie to include the low frequency performance in the design of housing, several obstacles would delay the process and make it difficult and strenuous to complete

The problems to overcome may be:

- How to specify the acoustic quality
- Lack of low-frequency test results for building components and constructions
- Lack of prediction models and design tools valid for low-frequency design
- Development of building components/systems with improved low frequency sound insulation
- Very little experience with test methods including low-frequency measurements
- High inaccuracy in design at low frequencies
- High inaccuracy of measurements at low frequencies
- Insufficient knowledge about correlation between objective and subjective sound insulation – especially related to the low frequencies
- Who should pay the increased costs for the first experiments?
- How much are the occupants willing to pay extra for better low-frequency sound insulation?

Unless "supported" by legal requirements or encouraged by acoustic classification systems it requires a substantial dedication to accomplish the task. Research as well as experiments are needed. Due to lack of experience, a classification system might be the most appropriate place to introduce the low-frequency C-corrections the first time, instead of a general implementation in the legal requirements. Lack of "support" implies lack of experience, which implies lack of progress, which might imply lack of acoustical comfort. The effects of noise on people at home are described in eg Grimwood (1993)

USES OF THE NEW ISO 717 RATING CONCEPTS IN CLASSIFICATION SYSTEMS

Rather than implementing the C-corrections in the building regulations, the consequences being that new product data and guidelines are required – especially for the low-frequency C-corrections – some countries might prefer to introduce the C-corrections in classification systems

In spite of the facts that a dwelling is probably the biggest investment during most people's lifetime, that much time is spent in the dwelling, and that acoustic comfort is very important to the well-being, objective information about the acoustic conditions is rarely available. This is very unsatisfactory to prospective occupants of a dwelling as acoustic quality is a 'hidden' quality, which is not easily evaluated by other means

An acoustic classification system for dwellings may have several uses:

- Information to consumers about the acoustic quality of a dwelling
- A tool to be used by consumers, building contractors and authorities to specify acoustic quality for new dwellings and for older dwellings to be renovated/restored.
- Emphasis on the fact that the legislative acoustic requirements are minimum requirements
- An incentive to voluntarily specify and design for better acoustic quality than required in the building regulations
- As part of a combined system (including several other aspects) for quality labelling of dwellings

An adequate system for acoustic classification of dwellings must primarily reflect different levels of acoustic quality correlating well with the occupants' subjective experience in everyday life. An inadequate system implies inconvenience to the occupants To the extent that the correlation between the objective and the subjective evaluation is improving significantly by applying the new C-corrections, they should be used in classification systems.

The perspective is that such classification systems will provide suitable information and specification tools for prospective occupants of dwellings, the building industry and the authorities

The low-frequency C-corrections are applied in the higher classes in the Swedish standard, cf SS 02 52 67 (1996), and probably in a new Nordic proposal being prepared

The Norwegian proposal, NBR F 32/96 (1996), is very interesting for several reasons. Besides dwellings, the proposal also includes acoustic classification of schools, offices, hospitals etc. The intention is to put into force the final standard simultaneously with the next, revised building code, which will probably include functional requirements rather than specific numeric criteria. Thus, another tool is needed for evaluation of compliance with the degree of functionality required by the building code The proposal recommends – but does not require – the low frequency performance to be taken into account by including the relevant spectrum adaptation terms in the criteria.

CONCLUSION

The most significant change in the upcoming ISO 717 methods is that measurement results at low frequencies (50–80 Hz) can – voluntarily – be included in the rating by applying the low frequency C-corrections defined in Annexes of the standards The need to include low frequencies in the rating of sound insulation – not necessarily in the way it is implemented in ISO/DIS 717 – is recognized in the Nordic countries.

From the analysis of 142 field measurements of impact noise level in the extended frequency range down to 50 Hz it has been found that the average C-correction $C_{i,50\text{-}2500}$ is -3.2 dB in the group of heavy constructions, +1.5 dB in the group of medium-weight constructions, and +2.4 dB in the group of light-weight constructions. It has been argued that negative values of the C-correction tend to be too optimistic and consequently should not be used.

A direct correlation with subjective evaluation has not been done. Instead 146 new results from field measurements of impact noise level have been correlated with the Bodlund-index L_B, which has earlier been shown to have higher correlation (r = 87%) than any other known criteria for impact sound. It is concluded that the L'_{nw} has only a weak correlation with L_B, whereas the inclusion of the low frequencies by adding the correction $C_{i,50\text{-}2500}$ improves the correlation significantly, namely from 76% to 96%.

There seem to be several obstacles to overcome, before the low-frequency C-corrections can be implemented in the building regulations, and more research and analyses of consequences are needed. The problems include among other things lack of low-frequency test results and prediction models for building components and constructions. Thus, there are several reasons for reluctance to full implementation of the new concepts, which – in addition – are not "simple" to understand. Rather than implementing the C-corrections in the building regulations, the consequences being that new product data and guidelines are required – especially for the low-frequency C-corrections – some countries might prefer to introduce the C-corrections in classification systems.

The way to proceed may be to link the building codes more closely with a classification system as has been proposed in Norway. The intention is to put into force the final standard simultaneously with a revised building code, which will probably include functional requirements rather than specific numeric criteria. Thus, another tool, eg a classification system, is needed for practical evaluation of compliance with the degree of functionality required by the building code. A system for acoustic classification of dwellings provides several advantages: (1) A tool to be used by consumers, building contractors and authorities to specify acoustic quality of new dwellings and of older dwellings to be renovated or restored; (2) Emphasis on the fact that the legislative acoustic requirements are minimum requirements; (3) An incentive to voluntarily specify and design for better acoustic quality than required in the building regulations.

In the long run, implementation of the low-frequency C-corrections in classification systems imply gain of experience, thus preparing the way for future implementation in the legal minimum requirements.

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APPENDIX A.
Description of spectrum adaptation term as defined in ISO/DIS 717-2

Purpose of standard

The purpose of ISO 717-2 is to standardize a method whereby the frequency dependent values of impact sound pressure level can be converted into a single number characterizing the acoustical performance The standard gives rules for determining single-number quantities from the results of measurements carried out in 1/3 octave or 1/1 octave bands according to ISO 140-6 and 140-7.

The single-number quantities calculated according to this part of ISO 717 are intended for rating the impact sound insulation and for simplifying the formulation of acoustical requirements in building codes

Generally, the single number is based on results of measurements in 1/3 octave bands Single numbers based on 1/1 octave band data may only be calculated from results of field measurements according to ISO 140-7

Spectrum adaptation term C_i

The spectrum adaptation term C_i has been introduced to take into account the unweighted impact sound pressure level, thereby representing the characteristics of typical walking spectra. The spectrum adaptation term C_i, which may be calculated for the frequency range 100-2500 Hz or for an enlarged frequency range down to 50 Hz, is defined and described in Annex A of ISO/DIS 717-2.

C_i has not been included directly in the single-number quantity but has been introduced as a separate correction.

Calculation of single-number quantities

To evaluate the results of a measurement according to ISO 140-6 and ISO 140-7 in 1/3 octave bands (or 1/1 octave bands) given to 0.1 dB, the relevant reference curve, cf the reference values below or Figures A.1-A.2, shall be shifted in steps of 1 dB towards the measured curve, until the sum of unfavourable deviations is as large as possible, but not more than 32.0 dB (measurement in 16 1/3 octave bands) or 10.0 dB (measurement in 5 1/1 octave bands). An unfavourable deviation at a particular frequency band occurs when the result is higher than the reference value. Only the unfavourable deviations are taken into account

The value, in dB, of the reference curve at 500 Hz – after shifting it according to this procedure – is $L_{n,w}$, $L'_{n,w}$ or $L'_{nI,w}$.

The reference values for determination of the single-number quantities $L_{n,w}$, $L'_{n,w}$ or $L'_{nI,w}$ for 1/3 octave band measurements are 62, 62, 62, 62, 62, 62, 61, 60, 59, 58, 57, 54, 51, 48, 45, 42 dB for the frequency range 100-3150 Hz. The values for 1/1 octave band measurements are 67, 67, 66, 62, 49 dB for the frequency range 125-2000 Hz. The reference values are shown graphically in Figures A.1-A.2

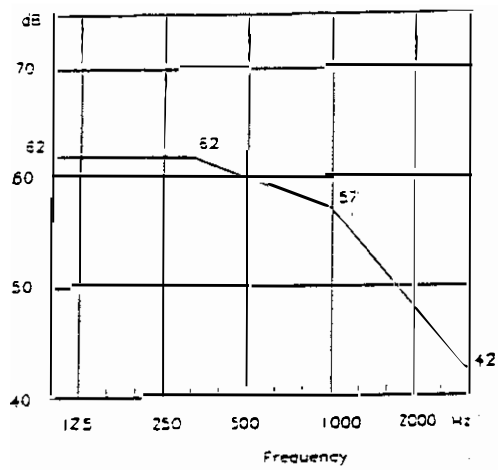

Fig. A.1. Curve of reference values for impact sound insulation measurements in 1/3 octave bands. Ref.: ISO/DIS 717-2 (1994).

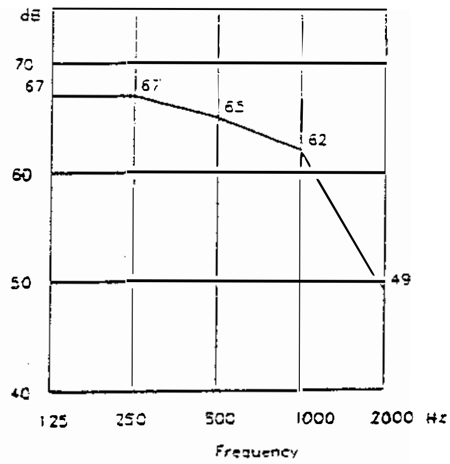

Fig. A.2. Curve of reference values for impact sound insulation measurements in 1/1 octave bands. Ref.: ISO/DIS 717-2 (1994).

Calculation of spectrum adaptation term C_i

$C_i = X_A - X_w$ [dB]

where

C_i Spectrum adaptation term.

X_w The single-number quantity, eg $L'_{n,w}$, calculated by comparing the measured values with the shifted reference curve. The procedure is the same as in ISO 717-2 (1982).

X_A Calculation made from: $X_A = 10 * \log \sum_{i=1}^{n} 10^{L_i/10} - 15$ $[dB]$

i Index for the 1/3 or 1/1 octave bands in the relevant frequency range.

L_i Measured impact sound level at the frequency band i, eg L'_n or L'_{nT}, given to 0.1 dB.

The number 15 in the calculation of X_A has been so determined that the value of C_i is approx 0 for solid floors with effective coverings.

The minimum frequency ranges to be applied for calculation of C_i-corrections are 100-2500 Hz and 125-2000 Hz for 1/3 and 1/1 octave measurements, respectively. In case that an enlarged frequency range is used, the frequency range has to be stated in the index of C_i.

The spectrum adaptation term is calculated according to 0.1 dB and rounded to an integer (+xy.5 is rounded to xy+1 and −xy.5 is rounded to −xy; see also ISO 31-0).

As an example, the spectrum adaptation term $C_{i,50\text{-}2500}$ for a 1/3 octave measurement of L'_n is calculated according to:

$$C_{i,50\text{-}2500} = 10 * \log \sum_{i=1}^{18} 10^{L_i/10} - 15 - L'_{n,w} \quad [dB]$$

Examples on statement of performance and of requirements

Example on statement of performance in buildings:

$L'_{n,w}$ (C_i; $C_{i,50\text{-}2500}$) = 48 (1; 3) dB

Examples on statement of requirements:

$L'_{n,w} \leq$ 50 dB; $L'_{n,w} + C_i \leq$ 50 dB; $L'_{n,w} + C_{i\,50\text{-}2500} \leq$ 50 dB