Translation of existing airborne sound insulation descriptors into proposed harmonized approach using in-situ measurements

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Abstract

A standard defining a common acoustic classification scheme for dwellings is under development by ISO TC42/SC2/WG29 based on the outcomes of European project COST Action TU0901. The proposal stands on the assumption that in the long term many countries will establish building acoustic requirements using a harmonized set of descriptors.
In this scenario most countries will need to estimate the influence on their current airborne sound insulation requirements due to the new descriptor. This paper investigates a statistical method to obtain translation equations between existing and proposed descriptors, based on the analysis of a significant set of in-situ measurements. Several translation equations are proposed, and the effect of the building system such as heavy and light weight walls.
Results show that, although it is possible to propose a single translation equation for each existent descriptor, in some cases the spread around the proposed translation line is significant. Overall, the effect of building system is more noticeable if different frequency range descriptors are involved in the translation.
For some existent descriptors, the obtained translation is compared with the theoretical method proposed within the findings of COST TU0901. When considering only lightweight walls or the full data set, there is no good agreement between both methods, but for heavyweight walls they converge.
Existing requirements in most European countries have been translated into the proposed descriptor $D_{nT,50} \approx D_{nT,w} + C_{50\text{-}3150}$ using the obtained equations. This provides valuable information and an insight for government and building regulation policy makers when updating their legislation.

1. Introduction

The protection against noise both outdoors and with-in the built environment is being increasingly demanded by experts and society as a consequence, among other factors, of the negative effects of noise, and drive to improve the quality of life within the work, educational and habitat environment. The negative effects of noise have been studied and outlined for some time. More recent reports have again summarized these findings such as the WHO Environmental Burden of Disease in Europe [1], the reports from Basner et al. [2,3], and several others.

In the field of building acoustics, the protection of citizens' health is covered by national regulations, but there is a growing demand by inhabitants for higher acoustic performance in order to obtain better levels of acoustic comfort. In several European countries, sound insulation classifications schemes are being developed or already entered into force, although *due to the lack of coordination among countries, a significant diversity in terms of descriptors, number of classes, and class intervals occurred between national schemes* [4]. Beyond defining acoustic classes according to different levels of sound insulation, developing a common classification scheme could stimulate the reduction of trade barriers, support further innovation in construction material systems and design and lead to multi-country improvement of the sound insulation of dwellings.

A European acoustic classification scheme with a number of quality classes was proposed within COST Action TU0901 European research and networking project [5], where 32 countries participated. Due to the existing high degree of diversity of regulatory requirements and descriptors [6,7], the proposed classification scheme [8] was based in a set of harmonized descriptors for airborne and impact sound insulation also proposed by the same action.

Simultaneously to the COST Action TU0901 proposal of harmonized descriptors, the revision of ISO 717 series [9,10] was being performed by ISO TC43/SC2/WG18. This revision aimed not only at harmonizing sound insulation descriptors (reducing the amount of possible sound insulation descriptors and pointing out the preferred ones), but also at providing alternative methods to determine single number quantities that would give answer to old and new technical and social demands [11]. One of the revised proposals suggested that the traditional ISO 717 weighting reference curves could be removed and other weighting methods introduced providing two alternative frequency ranges for airborne sound insulation evaluation: 50–3150 Hz, important for lightweight buildings, and most used 100–3150 Hz [12]. The ideal objective was to adopt a single number rating method that would characterize the sound insulation of buildings despite its heterogeneous frequency behaviour and would also take into account the subjective evaluation of annoyance produced by different sound sources.

No consensus was reached among participant countries and the ISO 717 revision was cancelled, encouraging experts to provide more conclusive research in the field to enlighten its main controversial topics. It is important to point out that in spite of not having come to an agreement in many aspects, there was a general agreement on the fact that often low frequency sounds are disturbing and thus it is important to provide sufficient protection against noise sources with strong low frequency content. Taking this into consideration, the recently reviewed sound insulation field measurement standards [13–15] have included a specific low frequency measurement procedure to be used under certain circumstances.

The debate is still open and relevant research is being done on different topics such as measurement procedures at low frequencies topics [16], effect of low frequency inclusion on measurement uncertainty assessment ratings [17–19] and subjective/objective aspects of sound insulation descriptors [20–23], just to mention some of the most recent studies related to the harmonization of sound insulation descriptors.

Given the difficulty found in coming to a perfect agreement on harmonized descriptors, the COST TU0901 Acoustic Classification Scheme - ACS - for dwellings proposal was designed using most agreed descriptors and preliminary proposing a frequency range assessment from 50 Hz. For airborne sound insulation the selected descriptors were $D_{nT,50} \approx D_{nT,w} + C_{50\text{-}3150}$ and/or $D_{nT,100} \approx D_{nT,w} + C_{100\text{-}3150}$.

Figure 1 presents the COST Action TU0901 ACS proposal. Advantages and justification for this proposal, including frequency range and assessment methods can be found in [5]. Due to the interest of this initiative, the proposal has been used as a draft input for developing a new ISO standard ISO/CD 19488 – Acoustic Classification Scheme for Dwellings [24].

Type of space	Class A $D_{nT,50}$ (dB)	Class B $D_{nT,50}$ (dB)	Class C $D_{nT,50}$ (dB)	Class D $D_{nT,50}$ (dB)	Class E $D_{nT,50}$ (dB)	Class F $D_{nT,50}$ (dB)
Between a dwelling and premises with noisy activities (3)	≥ 68	≥ 64	≥ 60	≥ 56	≥ 52	≥ 48
Between a dwelling and other dwellings and rooms outside the dwelling	≥ 62	≥ 58	≥ 54	≥ 50	≥ 46	≥ 42

NOTES

(1) $D_{nT,50} = D_{nT,w} + C_{50\text{-}3150}$;

(2) As an alternative to $D_{nT,50}$, the performance can be estimated for all types of construction by the currently more common descriptor $D_{nT,100} = D_{nT,w} + C$, see clause 3. If $D_{nT,100}$ is applied, the class denotation is X_{100}, eg. B_{100}.

(3) Premises with noisy activities are rooms for shared services like laundries, central boiler house, joint/commercial kitchens or commercial premises like shops, workshops or cafés. However, in each case, noise levels must be estimated and the sound insulation designed accordingly, e.g. for party rooms, discotheques etc. Offices are normally not considered as noisy premises, and the same criteria as for dwellings apply.

Figure 1: Class criteria for airborne sound insulation as proposed by COST TU0901. From Chapter 5 [5]**.**

In order to adopt a classification scheme, it is necessary to translate existing descriptors into new harmonized ones. These translations have already been studied within the COST TU0901 project [25–27] although only references [12,27] present results for performing such translations. In reference [28] Gerretsen and Dunbavin present two different proposals, one based on basic building acoustics equations, and the other using a similar approach as the one presented in this paper. This last approach will be described in section 4 and consists in determining correlations between different descriptors and obtaining the correspondent translation equations. Reference [27] points out the need of studying the problem more deeply since only data from a few lightweight walls were included their research.

2. Objectives

Elaborating and proposing a classification scheme for dwellings which could be used all over Europe (CEN countries) or even in a great part of the world (ISO countries) is an ambitious objective. The adoption of such proposal is very difficult to achieve unless the corresponding authorities and policy makers can easily translate the existing requirements into new proposed sound insulation descriptors. Policy makers are required to adequately evaluate the effects and consequences of adopting new proposed standards and classification schemes in their country. This is often undertaken as part of the 'impact of proposed changes' within the policy development and wider consultations with industry.

This paper aims at providing valuable evidence for the "airborne sound insulation descriptors translation procedure". Most of the existent European airborne sound insulation descriptors and requirements have been translated into the proposed harmonized ones ($D_{nT,50} \approx D_{nT,w} + C_{50-3150}$ and/ $D_{nT,100} \approx D_{nT,w} + C_{100-3150}$). This translation will undoubtedly be a valuable tool for national authorities and industry organisations to interpret how the proposed acoustic classification scheme would affect the existing legislation and reporting boundaries.

The main objectives of the paper can then be summarized as follows:

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- Based on a large set of in-situ airborne sound insulation measurements, to propose updated translation equations between existing airborne sound insulation descriptors and proposed ones $D_{nT,50}$ and $D_{nT,100}$;
- To compare the obtained translation equations with those proposed by Gerretsen in [27,28];
- To investigate translation effects for heavy and light weight walls;
- For thirty two countries, to deliver their current airborne sound insulation national requirements translated into $D_{nT,50}$;
- For the same countries, to evaluate their possible position in the acoustic classification scheme proposed by COST Action TU0901.

3. Data set description

The input data consisted on a set of over 1000 field airborne sound insulation measurements involving 9 different types of separating walls (7 heavyweight and 2 lightweight). All walls were constructed in the United Kingdom in compliance with the relevant Robust Details [29] specifications. The construction system of the seven types of heavyweight walls (from 1 HW to 7 HW) and the two types of lightweight walls (1 LW and 2 LW) is summarized in Figures 2, 3 and 4.

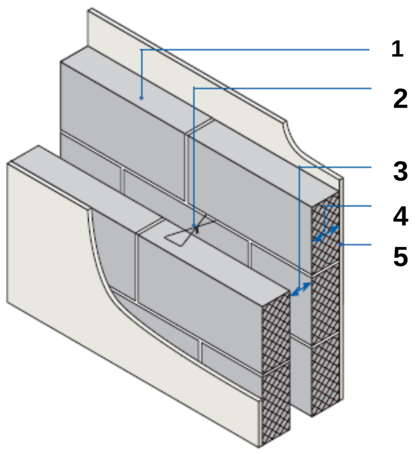
<table>
<tr><td colspan="2">Heavyweight walls</td></tr>
<tr><td>Plaster finished walls</td><td>5- Wall finish : 13mm plaster or cement both sides</td></tr>
<tr><td rowspan="3">
</td><td>1 HW
1- Dense aggregate Block (1850 to 2300 Kg/m^3)
2- Wall Ties
3- Cavity width 75mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
<tr><td>2 HW
1- Light weight aggregate Block (1350 to 1600 Kg/m^3)
2- Wall Ties
3- Cavity width 75mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
<tr><td>3 HW
1- Light weight aggregate Block (1850 to 2300 Kg/m^3)
2- Wall Ties
3- Cavity width 100mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
</table>

Figure 2: Construction system of plaster finished heavyweight walls.

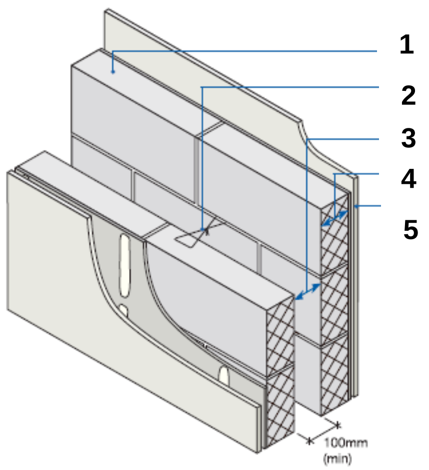
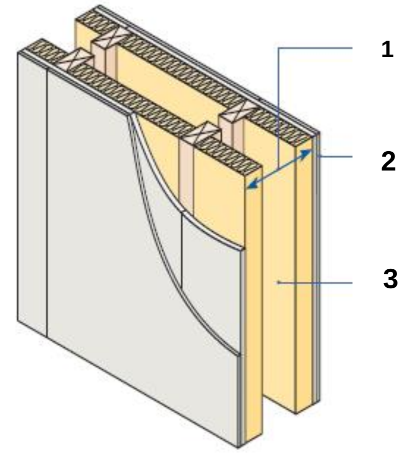
<table>
<tr><td colspan="2">Heavyweight walls</td></tr>
<tr><td>Gypsum board finished walls</td><td>5- Wall finish : gypsum-based board (nominal 8 kg/m2) mounted on dabs on cement</td></tr>
<tr><td rowspan="4">
</td><td>4 HW
1- Dense aggregate Block (1850 to 2300 Kg/m^3)
2- Wall Ties
3- Cavity width 75mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
<tr><td>5 HW
1- Light weight aggregate Block (1350 to 1600 Kg/m^3)
2- Wall Ties
3- Cavity width 75mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
<tr><td>6 HW
1- Light weight aggregate, or Hollow or cellular blocks (1350 to 1600 Kg/m^3)
2- Wall Ties
3- Cavity width 100mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
<tr><td>7 HW
1- Light weight load bearing blocks (1050 Kg/m^3)
2- Wall Ties
3- Cavity width 75mm (min)
4- Block thickness 100mm (min), each leaf</td></tr>
</table>

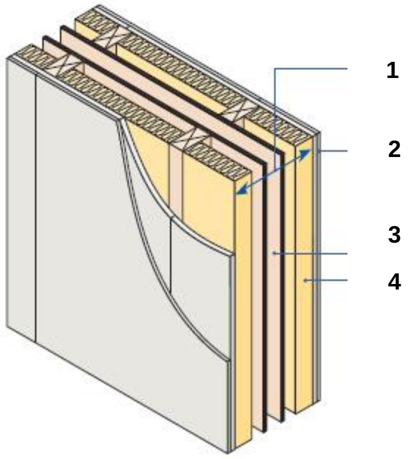
Figure 3: Construction system of gypsum board finished heavyweight walls.

Lightweight walls



1 LW

1- 240mm (min) between inner faces of wall linings. 50mm (min) gap between studs
2- Wall lining: 2 or more layers of gypsum-based board (total nominal mass per unit area 22 kg/m^2), both sides
3- 60mm (min) mineral wool material batts or quilt (density 10 – 60 kg/m^3) both sides.



2 LW

1- 240mm (min) between inner faces of wall linings. 50mm (min) gap between studs
2- Wall lining: 2 or more layers of gypsum-based board (total nominal mass per unit area 22 kg/m^2), both sides
3- Sheathing: 9mm (min) thick board
4- 60mm (min) mineral wool material batts or quilt (density 10 – 60 kg/m^3) both sides.

Figure 4: Construction system of lightweight walls

Tables 1 and 2 show the number of samples, average and standard deviation for $D_{nT,50}$ for each of the wall types considered in this study. Figure 5 and Table 3 show the probability density values, average and standard deviation for $D_{nT,50}$ considering the full data set. All $D_{nT,50}$ average values are above 56 dB and, for the full data set, the average is close to 58 dB so it can be said that it is a set of mainly well performing walls.

Table 1: Heavyweight walls data set information

Heavy walls	Total	1 HW	2 HW	3 HW	4HW	5 HW	6HW	7 HW
Average $D_{nT,50}$ (dB)	57,80	57,45	57,40	58,75	57,40	59,30	56,15	57,00
Standard deviation (dB)	4,10	3,70	3,85	4,45	4,00	4,20	3,75	2,70
No of samples	654	53	63	110	337	69	13	9

Table 2: Lightweight walls data set information.

Lightweight walls	Total	1 LW	2 LW
Average $D_{nT,50}$ (dB)	58,10	58,25	57,90
Standard deviation (dB)	3,60	3,50	3,80
No of samples	445	245	200

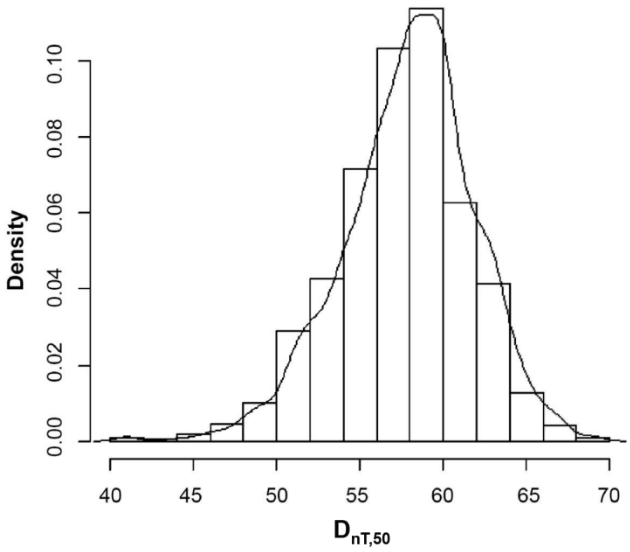


Table 3: Full data set information.

Average $D_{nT,50}$ (dB)	57,97
Standard deviation (dB)	3,94
No of samples	1099

Figure 5: Probability density values of $D_{nT,50}$ (full data set).

4. Translation of most commonly used single number descriptors of airborne sound insulation into $D_{nT,50}$ / $D_{nT,100}$

As explained by Gerretsen and Dunbavin [28], the translation between different sound insulation descriptors is not a simple task and appears to depend on the type of building. In reference [27] Gerretsen suggests a translation between descriptors based on a two steps procedure:

Step one: translation between descriptors according to equation (1). A compromise value for the receiving room volume V=52,5 m^3 and the volume/area ratio V/S=2,5 m was used.

$$D_{nT} = R' + 10\log\frac{0.16V}{T_0\ S_s} \tag{1}$$

Step two: translation between weighting procedures. This second step was based on a previous study performed by Scholl et al. considering only heavyweight walls [12].

In this paper a different approach is proposed and the translation equations are obtained from the statistical correlations between existent descriptors and the ones proposed for the common classification scheme: $D_{nT,50}$ / $D_{nT,100}$.

The calculations have been performed according to the following steps:

- Using the data of the complete set of airborne sound insulation measurements (1.099), the seven most adopted single number descriptors for airborne sound insulation around Europe [7] were calculated (that is R'_w ; $R'_w + C$; $R'_w + C_{(50\text{-}3150Hz)}$; $D_{nT,w}$; $D_{nT,w} + C_{tr}$; $D_{nT,w} + C$; $D_{nT,A\ (100\text{-}5KHz)}$)
- $D_{nT,50}$ and $D_{nT,100}$ were also calculated.
- Pearson correlation coefficient between $D_{nT,50}$ / $D_{nT,100}$ and the seven airborne sound insulation descriptors was calculated. Results are presented in Table 4 for the complete dataset "All" and also sub categorized in "Heavy" and "Light". This terminology will be used hereinafter when referring to results obtained from the corresponding restricted data set (only heavyweight walls, only lightweight walls or the full data set).
- Finally, a scatter plot and a simple linear regression between $D_{nT,50}$ / $D_{nT,100}$ and each of the previously selected descriptors was made. These linear regressions are in fact the corresponding "translation equations" between each pair of descriptors. Table 5 presents the obtained translation equations if only a restricted data set is considered (either measurement on heavy or on light walls). In this case two different linear regressions ("translation equations") are obtained for each pair of descriptors. Table 6 presents the obtained translation equations when using the full data set as well as the translation equations proposed by Gerretsen et al. (from now on labelled as Gerretsen) in [28].

Table 4 – Pearson correlation coefficient between existent descriptors and new ones

(y)	(x)	R'_w	$R'_w + C$	$R'_w + C$ (50-3150Hz)	$D_{nT,w}$	$D_{nT,w} + C_{tr}$	$D_{nT,w} + C$	$D_{nT,A}$ (100-5KHz)
$D_{nT,50}$	All	0,74	0,78	0,90	0,81	0,87	0,87	0,86
	Heavy	0,89	0,90	0,91	0,96	0,95	0,98	0,98
	Light	0,60	0,66	0,89	0,70	0,72	0,76	0,76
$D_{nT,100}$	All	0,90	0,92	0,78	0,97	0,93	1,00	1,00
	Heavy	0,91	0,92	0,89	0,99	0,96	1,00	1,00
	Light	0,84	0,89	0,68	0,94	0,93	1,00	1,00

If the Pearson correlation coefficients shown in Table 4 are analysed, it is found that the values are always smaller for lightweight walls than for heavyweight walls. This indicates that, for lightweight walls, the spread of the data around the lineal regression equation will be wider. Furthermore, in Table 5 it is possible to observe that the translation between descriptors is not completely independent on the building system and different equations are found when considering heavy and light weight walls separately.

Table 5 - Translation equations between descriptors for the categorized data.

(x) \ (y)	Type of Walls	$D_{nT,50}$	$D_{nT,100}$
R'_w*	Heavy	y = 0,82x + 9,95	y = 0,87x + 7,54
	Light	y = 0,58x + 22,00	y = 0,81x + 11,17
$R'_w + C$	Heavy	y = 0,85x + 9,25	y = 0,91x + 7,07
	Light	y = 0,64x + 19,89	y = 0,86x + 9,96
$R'_w + C_{(50\text{-}3150Hz)}$	Heavy	y = 0,90x + 7,32	y = 0,92x + 7,09
	Light	y = 0,88x + 8,59	y = 0,67x + 23,67
$D_{nT,w}$*	Heavy	y = 0,89x + 4,74	y = 0,95x + 2,06
	Light	y = 0,70x + 13,57	y = 0,95x + 1,51
$D_{nT,w} + C_{tr}$*	Heavy	y = 0,97x + 6,03	y = x + 4,52
	Light	y = 0,69x + 19,99	y = 0,89x + 12,62
$D_{nT,w} + C$*	Heavy	y = 0,94x + 3,73	y = x + 1,13
	Light	y = 0,76x + 12,13	y = x + 1,34
$D_{nT,A\ (100\text{-}5KHz)}$	Heavy	y = 0,94x + 2,97	y = x + 0,23
	Light	y = 0,76x + 11,32	y = x + 0,17

*Comparison of the translation equations of these descriptors to $D_{nT,50}$ and Gerretsen proposal is represented in Figure 7

In most cases, there is a significant difference between the resulting translation equation for heavy/light weight solutions when $D_{nT,50}$ is considered whereas this is not so significant when considering $D_{nT,100}$. Since the majority of the existing descriptors use an assessment frequency range starting at 100 Hz, this indicates that as long as the assessment frequency range remains unchanged, there are no significant differences between the translation equations found for heavy and light walls. As can be observed in Table 5, this is also the case for descriptors using assessment frequency range starting at 50 Hz, that is translated from $R'_w + C_{(50\text{-}3150Hz)}$ to $D_{nT,50}$.

Since one of the main objectives of this paper is to propose updated translation equations between existing airborne sound insulation descriptors and the proposed $D_{nT,50}$ and $D_{nT,100}$, it is necessary to evaluate whether it is reasonable to use the same equation independently of the building system or if a different translation equation should be obtained for each construction type. Table 6 summarizes the corresponding translation equations obtained when considering the full data set.

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Table 6 – Single translation equations between descriptors, considering the full data set

(y) / (x)	$D_{nT,50}$	$D_{nT,100}$	Gerretsen
R'_w*	y = 0,63x + 20,23	y = 0,83x + 9,60	y= 0,88x+4,2
R'_w + C	y = 0,71x + 16,89	y = 0,90x + 7,40	
R'_w + C (50-3150Hz)	y = 0,89x + 7,77	y = 0,85x + 12,30	
$D_{nT,w}$*	y = 0,71x + 14,77	y = 0,92x + 3,63	y= 0,88x+5,08
$D_{nT,w}$ + C_{tr}*	y = 0,85x + 12,02	y = x + 5,83	y=0,88x+9,48
$D_{nT,w}$ + C*	y = 0,80x + 11,02	y = x + 1	y=0,88x+5,96
$D_{nT,A}$ (100-5KHz)	y = 0,79x + 10,64	y = x + 0,23	

*Comparison of the translation equations of these descriptors to $D_{nT,50}$ and Gerretsen's proposal is represented in Figure 9

Looking at the column for $D_{nT,100}$ both in Table 5 and 6, it is found that, for each existing descriptor (x), the translation equations in both tables show a fairly good agreement between them. In this case the translation does not seem to be strongly dependent on the building system and therefore it is suggested that the $D_{nT,100}$ translation equations obtained in Table 6 could be used regardless of the building system. Unfortunately this is not the case when $D_{nT,50}$ is considered. In the next section the results obtained for $D_{nT,50}$ are further investigated.

5. Evaluating $D_{nT,50}$ translation equations and comparising to existing proposal

In this section the difference between each pair of equations (heavy/light) shown in Table 5 for $D_{nT,50}$ is investigated and is undertaken in two stages.

As a first step, in section 5.1 the differences between heavy and light weight walls translation equations found in Table 5 are evaluated. When available, a comparison with Gerretsen's proposal [28] is also included.

The second step, presented in section 5.2, aims at evaluating if, for each descriptor, it is acceptable to use one single translation equation regardless of the building system, and how close is the proposed translation equation to Gerretsen's proposal.

The legend for all the figures presented in this section is as follows:

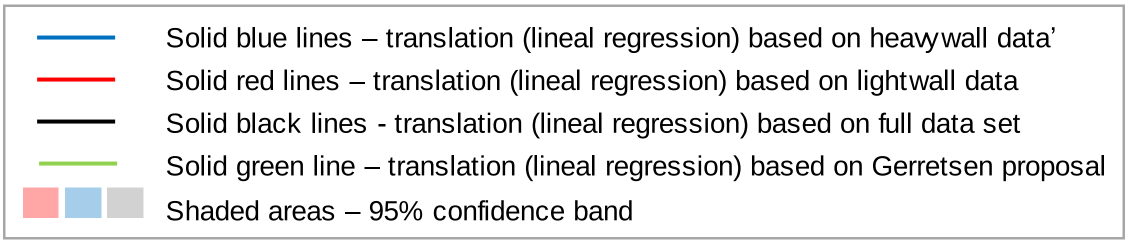

Figure 6: Legend for figures 7, 8 and 9.

5.1 Translation equations obtained for different building systems

Although the pair of equations shown in Table 5 for each set of descriptors may seem different, when considering certain confidence intervals, both equations would lie within the same limits. To verify this point, Figures 7 and 8 represent the corresponding pairs of regression lines including the 95% confidence intervals.

The descriptors having a translation proposal by Gerretsen (R'_w, $D_{nT,w}$, $D_{nT,w} + C_{tr}$, $D_{nT,w} + C$ and $D_{nT,50}$) are shown in Figure 7 together with the corresponding Gerretsen's proposal. The remaining descriptors ($R'_w + C$, $R'_w + C_{(50\text{-}3150Hz)}$ and $D_{nT,A\ (100\text{-}5KHz)}$) are represented in Figure 8.

As can be observed in Figures 7 and 8, the translation equations obtained using heavy weight walls and light weight walls separately, including the 95% interval confidence bands, only overlap within a very small range, which varies depending on the descriptor. In fact, both equations can be considered different for all descriptors except for $R'_w + C_{(50\text{-}3150Hz)}$ [Figure 8 b)].

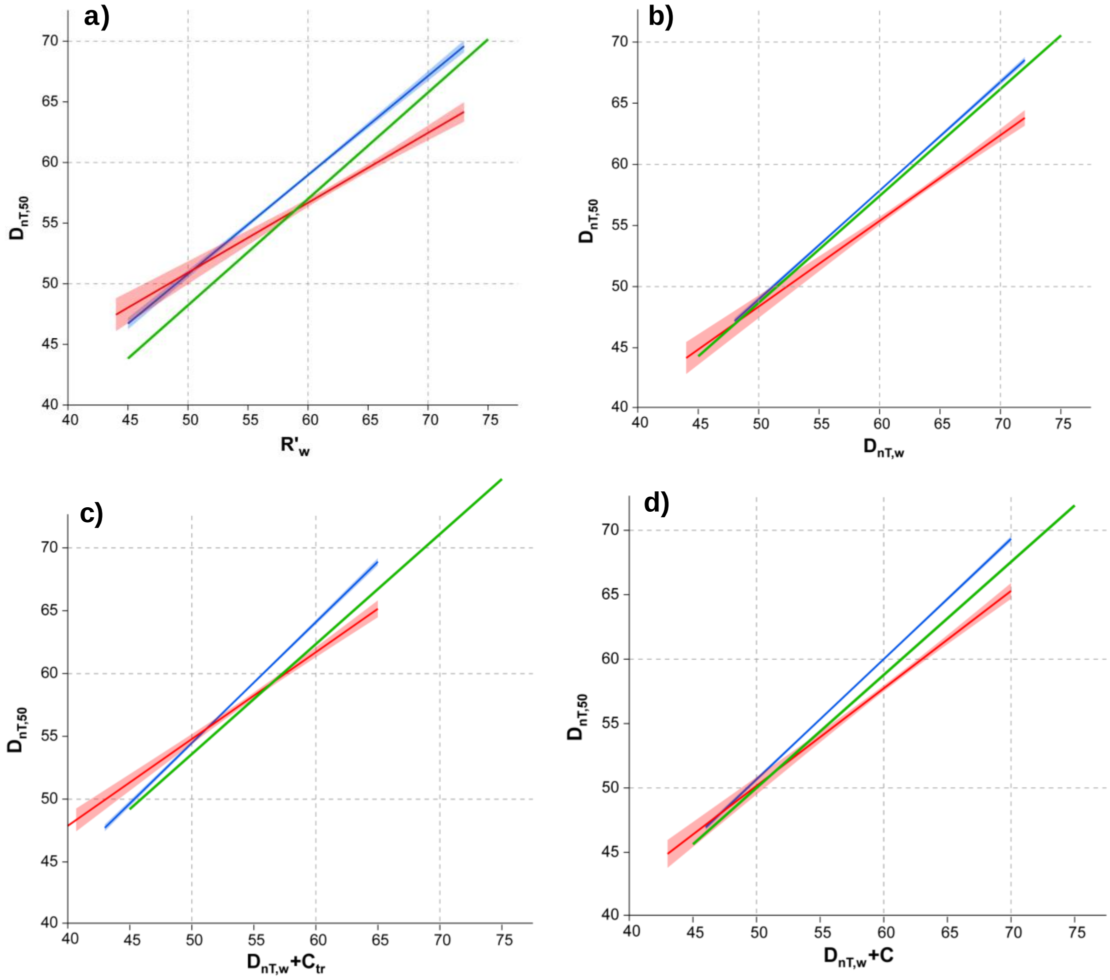

Figure 7: Comparison of translation equations obtained for different building systems and the existent proposal (Gerretsen).

Due to the effect of the spectral adaptation term $C_{(50\text{-}3150Hz)}$, the corresponding effective frequency range assessment in this case is the same as for $D_{nT,50}$, that is, from 50 Hz to 3150 Hz. This indicates the relevance of the assessment frequency range when calculating airborne sound insulation descriptors.

In general, for all the other descriptors, the heavyweight and the lightweight equations converge only for airborne sound insulation values (x axis) around 48-51 dB. For higher values (x axis), the corresponding differences between the heavy/light translated values (y axis) increase significantly, although differently depending on the pair of descriptors.

In Figure 7 the heavy/light regression lines are also compared to Gerretsen's translation proposal. It can be observed that there is fairly good agreement between the translation equations obtained using only the heavyweight walls and Gerretsen's proposal for those airborne sound insulation descriptors, based on level difference b), c) and d). For R'_w, a), the differences are more evident. This behaviour will reappear in section 5.2 and thus will be further analysed in that section.

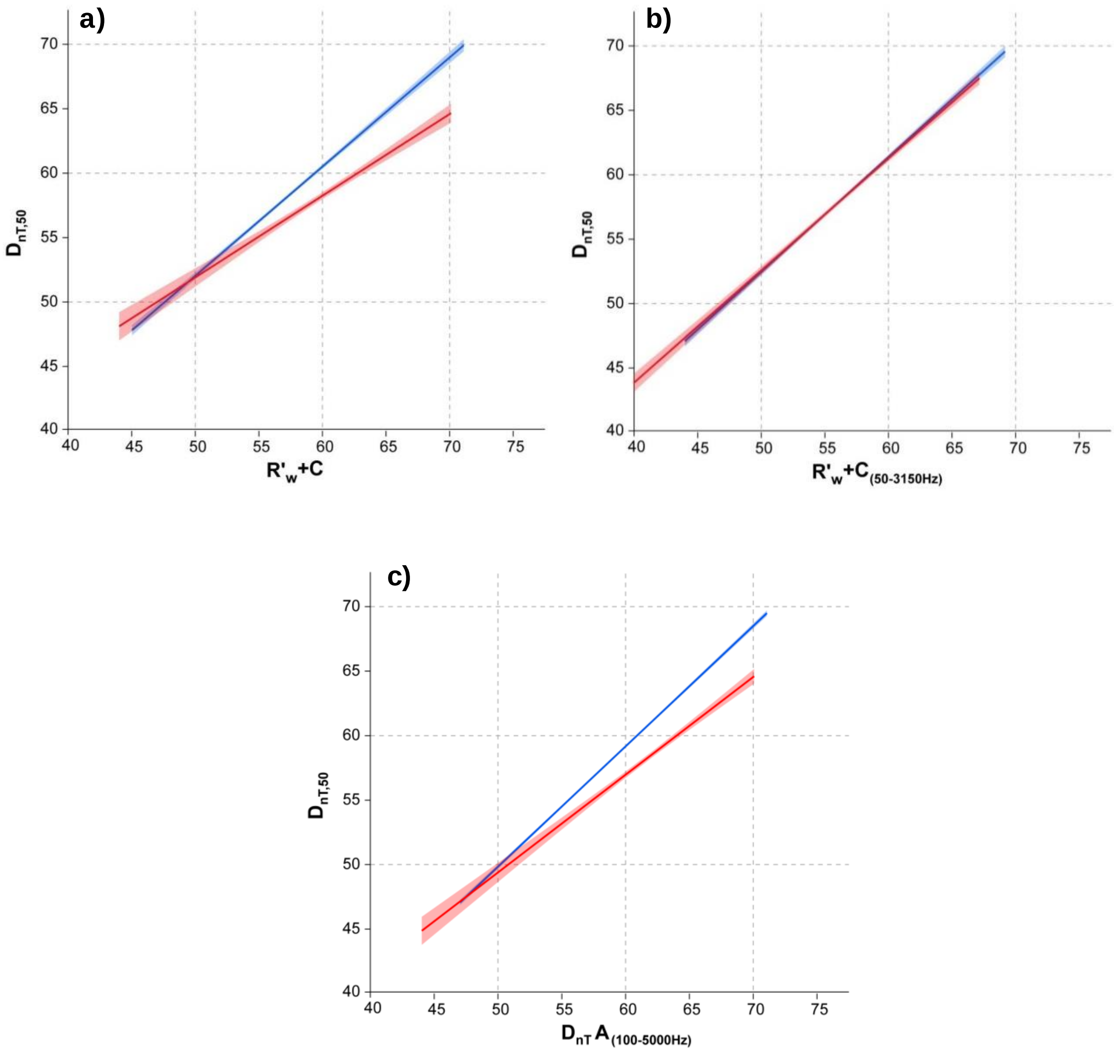

Figure 8: Comparison of the translation equations obtained for different building systems.

5.2 Single translation equations – independent of the building system

In the previous section it has been shown that there is a dependence on the building type when trying to translate existing airborne sound insulation descriptors into new proposed descriptors. Nevertheless, from a practical point of view, it can be convenient to propose a single translation equation which could be used regardless of the building system. The proposal is to use, in a preliminary stage, the translation equations obtained with the full data set (Table 6) and verify how these equations converge to Gerretsen's proposal.

Figure 9 represents the obtained single translation equations for the descriptors marked (*) in Table 6, with the 95% confidence band. Gerretsen's proposal and the scatter data are also included in the plots.

Plots a), b), c) and d) represent the linear regression between R'_w, $D_{nT,w}$, $D_{nT,w} + C_{tr}$, $D_{nT,w} + C$ and $D_{nT,50}$, according to both proposals.

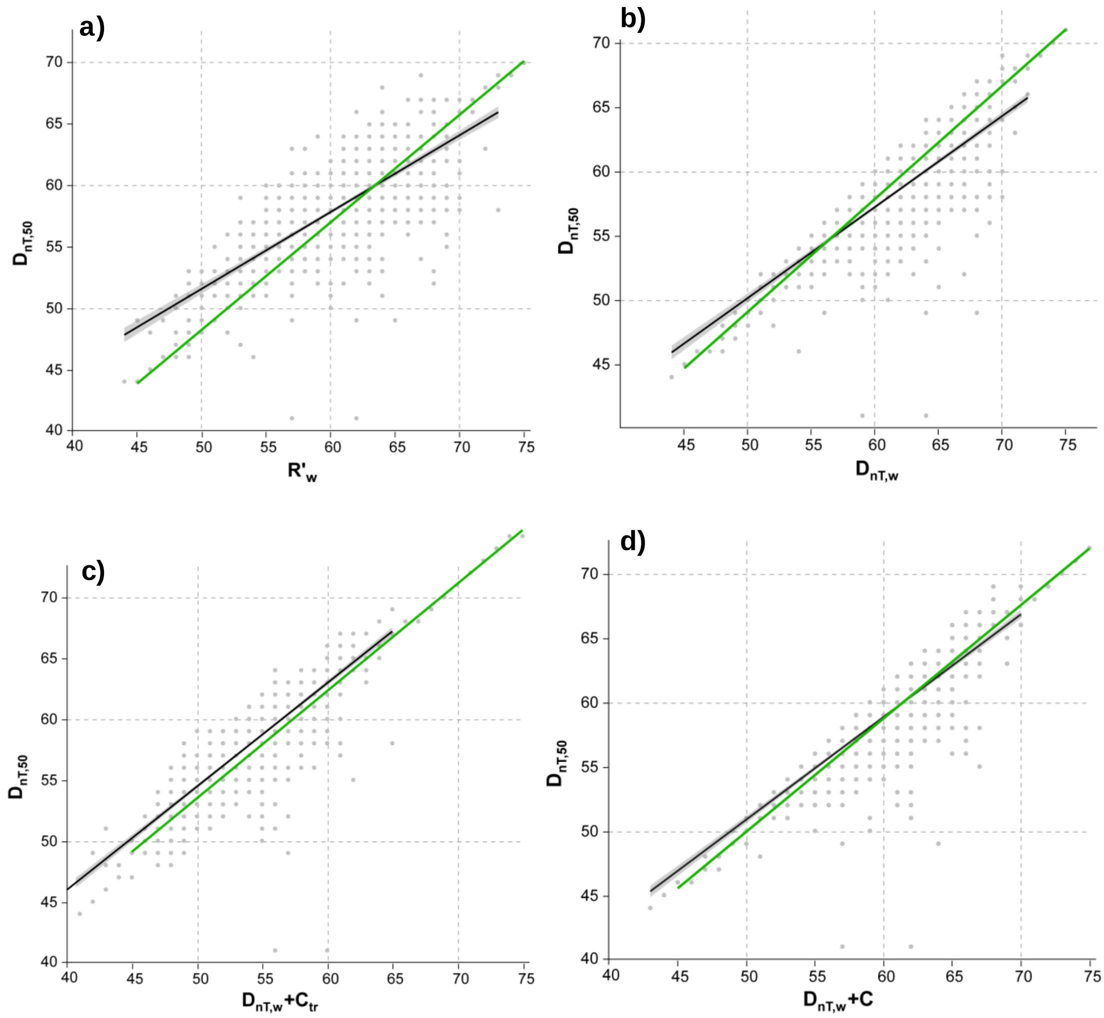

Figure 9: Comparison of obtained single translation equations and Gerretsen's proposal

As observed in section 5.1, the translations between descriptors based on level difference [plots b), c) and d)] show small differences with Gerretsen's proposal, with deviations of ±2 dB. This is not the case for the translation from R'_w to $D_{nT,50}$ (plot a), where the differences can reach up to ±5 dB.

The differences found between the statistical approach presented in this paper and the proposal made by Gerretsen can be due to divergences found between the underlying hypothesis in Gerretsen's proposal and the *in-situ* 'actual buildings' statistical data source.

In Gerretsen's proposal, a compromise value for the receiving room volume V=52,5 m^3 and the volume/area ratio V/S=2,5 was used. In the present study, a large data set of in-situ measurements was used to obtain the translation, including different construction types. For the 1099 in-situ tests, the typical volume average was V=35,3 m^3 and the typical volume/area ratio was V/S =3,8. These values correspond better with common spaces found in 'actual buildings' (e.g. average volume room 3,2 x 6,0 x 1,8 = 35m^3 and average common surface wall 5,0 x 1,8 =9 m^2).

6. Evaluation and influence of translated airborne sound insulation requirements within a proposed acoustic classification scheme

Adopting a common acoustic classification scheme based on harmonized descriptors is a policy decision which can have influence on future design and specifications leading to economic impacts. Legislators in each country need to evaluate the effects of the potential change and this cannot be assessed without a proper translation of existing sound insulation requirements into to the new harmonized descriptors. It is also important for legislators to evaluate which sound classification the translated requirement will align to and if this represents a change from the existing situation. In countries having an acoustic classification scheme for buildings, the sound insulation requirements often have lower classification grades or levels for older or renovated existing buildings and higher classes for more recently built buildings. This should remain unchanged in the potential new scenario. This is an important factor considering that sound insulation is often widely adopted within overall sustainability requirements or guidance of recent building standards in some European countries.

In this section the existing airborne sound insulation requirements in most European countries have been translated to the new suggested descriptor $D_{nT,50}$ and then placed within the proposed acoustic classification scheme for dwellings shown in Figure 1.

The translation has been performed based on the equations obtained in Table 6 (that is, using the full data set). The results are shown in Figure 10. As might be expected, most countries' requirements are located in the centre of the classification scheme (classes C and D) although there are important differences between countries. For example, some countries like Portugal and Spain would have an equivalent requirement $D_{nT,50}$ > 50, whereas others like Denmark, Sweden or Switzerland require $D_{nT,50}$ > 55.

Country	Currently descriptor and requirement		Translated requirements in $D_{nT,50}$ and classes from the proposal of classification scheme [5]
Bulgaria	R'_w	53	54
Croatia		52	53
Czech Rep.		53	54
Denmark		55	55
Estonia		55	55
Finland		55	55
Germany		53	54
Greece		50	52
Iceland		55	55
Italy		50	52
Latvia		54	54
Lithuania		55	55
Norway		55	55
Romania		51	52
Serbia		52	53
Slovakia		53	54
Slovenia		52	53
Hungary	$R'_w + C$	51	53
Netherlands		52	54
Poland		50	52
Sweden	$R'_w + C_{(50Hz-3150Hz)}$	53	55
Austria	$D_{nT,w}$	55	54
Belgium		54	53
Ireland		53	52
Lithuania		55	54
Portugal		50	50
GB-Scotland		56	55
Slovakia		53	52
GB-Eng&Wales	$D_{nT,w} + C_{tr}$	45	50
France	$D_{nT,w} + C$	53	53
Switzerland		55	55
Spain	$D_{nT,A}$ (100Hz-5000Hz)	50	50

F	E	D	C	B	A
42	46	50	54	58	62

Figure 10: Countries' airborne sound insulation requirements, corresponding $D_{nT,50}$ translation and alignment within the common acoustic classification scheme proposal

From the results in Figure 10, it is possible to estimate what would be the effect of adopting $D_{nT,50}$ as airborne sound insulation descriptor in all the countries illustrated. It is worth mentioning that a common sound classification scheme may help improving sound insulation of dwellings as it enables an international comparative and interchange of knowledge about the performance of acoustic conditions around different countries. This assists multi-national operating companies and also SME businesses exporting to different countries.

7. Conclusions

Based in a large data set of *in-situ* measurements of airborne sound insulation, and using a statistical approach, this study proposes translation equations between most of existing airborne sound insulation descriptors and the two most likely to be adopted in the future, $D_{nT,50}$ and/or $D_{nT,100}$.

Different translation equations have been obtained for different construction systems, classified in heavy and light weight as well as single equations based on complete data set.

From the results it can be observed that, when considering the translation of existing descriptors into the proposed $D_{nT,100}$, the resulting translation equations using differentiated data sets (heavy/light separately) or the full data set, are very similar as long as the assessment frequency range is not extended. This is the case of $R'_w + C_{(50\text{-}3150Hz)}$, the only existent descriptor evaluated that incorporates a frequency range that starts at 50 Hz, and which translations into $D_{nT,100}$ present significant differences for differentiated data sets based equations. This indicates that it is more critical for the translation process to change from one frequency range to another than changing from a sound reduction (R') criteria to a normalised difference (D).

For translations into $D_{nT,50}$, as the assessment frequency range is extended for the majority of the descriptors, there is no agreement both for heavy and light weight systems. Due to the assumptions taken into account in the theoretical method explained in section 5.2, translations obtained from “heavy” data are more in agreement with Gerretsen’s proposal. Differences between translations based on “heavy” or “light” data can reach up to 5dB. If in a country the performance of two different walls (one heavyweight and the other lightweight) is the same when using the existing descriptor, the heavy wall stated performance will overestimate (or the light wall underestimate) by 5dB if they are reported with the translated descriptor $D_{nT,50}$ based on the construction system. This was also demonstrated by Smith et al [30] using a very small sub-set of *in-situ* data of different construction types.

The obtained single translation equations are in agreement with the findings obtained by Gerretsen and Dunbavin [27]. The statistical method converges with the theoretical translation on average when $D_{nT,w}$, $D_{nT,w} + C_{tr}$ and $D_{nT,w} + C$ are translated into $D_{nT,50}$. For R'_w, the two methods don’t converge on average, probably due to the more significant differences observed for the translation based in “heavy” and “light” data for this descriptor.

Also in agreement with Gerretsen and Dunbavin results, it was observed that a spread around the average translation occurred when the statistical method was employed. But what stands out most is that the spread obtained from the translation using the substantial data set of this study is even larger. As mentioned above, the spread of the values needs to be considered as they might incur in several practical consequences.

One of the main objectives of this paper is to provide updated translation equations based on *in-situ* 'actual buildings' statistical data source. The obtained outcomes also give input to stakeholders to estimate the consequences of adopting an alternative airborne sound insulation descriptor that therefore would be adopted in a common acoustic classification scheme. For example, it is possible to estimate what would be the acoustic performance of their most typical constructions if expressed using the new descriptor.

Considering that translation equations from Table 6 can be employed to some extent, the airborne sound insulation requirements from 32 countries have been translated into $D_{nT,50}$ and aligned within the common acoustic classification scheme proposal. This enables acousticians, manufacturers and policy makers from different countries to compare their requirements with other countries and can give support for future improvements of national regulations and development of new building systems.

It is highly recommended that a similar study is undertaken with more data and with in-situ airborne sound insulation data from a variety of different countries' typical constructions. It is also necessary to perform a more thorough investigation in order to identify in which cases a single translation equation could be used independently of the building system.

If this is not achieved then it will be necessary to use different translation equations depending on the building system. This is a pathway that regulators and policy makers would wish to avoid in order for all build systems to be treated fairly.

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