Review and Synthesis of ISO 717 Airborne Sound Insulation Criteria

Image is of Merchiston Tower - original home of John Napier
Merchiston Campus, Edinburgh Napier University

John Napier was a sixteenth century mathematician and philosopher who invented logarithms and was born in Merchiston Tower, Edinburgh in 1550.

EURO GYPSUM
THE VOICE OF THE EUROPEAN GYPSUM INDUSTRY

Author: Professor Sean Smith

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Institute for Sustainable Construction, Edinburgh Napier University, 42 Colinton Road

Edinburgh, EH10 5BT, Scotland, UK

www.napier.ac.uk/isc
Email: se.smith@napier.ac.uk

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Edinburgh Napier UNIVERSITY

EXECUTIVE SUMMARY

This review was requested by Eurogypsum on behalf of its member companies and organisations to summarise and review the airborne sound insulation criteria specific to ISO 717 Part 1 and the potential measures of extending to lower frequencies below 100Hz. The main areas of work involved the encapsulation of recent published journal papers, conference papers and technical reports. The majority of the papers reviewed were undertaken during the last 6 years however, further papers were also reviewed which span back to the 1990's which also related to this subject area. The rationale behind such a review was to summarise the breadth and diversity of experts' findings, data analysis and also to examine the evidence and findings on which future decisions may be based by a possible future redesign of ISO 717 Part 1.

Encompassed within this review is the possible influence of such changes as expressed by various authors from an 'evidence based' approach. Issues such as extending low frequencies, influence for on-site testing, functional limitations, influence on reported construction performance (heavy and light) and importantly the influence on privacy and quality of life for housing occupants are discussed. This report has focused mainly on 'evidence based' materials. At present there is not sufficient weight of evidence, research, analysis or complaints compiled which supports the immediate inclusion of lower frequencies below 100 Hz for airborne sound insulation. That is not to say that complaints do not occur, but such evidence is required before national standards criteria can be altered and new criteria absorbed into standards. Of particular concern is the potential diminishing of privacy or quality of life by the negative effect on mid and high frequencies if a criteria is utilised which places too much emphasis on low frequencies.

Further research is required in this area to establish an appropriate approach, methodology and criteria which can adequately reflect the occupant and 'un-wanting' listener's exposure to current living noises.

1.0 Introduction

1.1 Airborne sound insulation is commonly measured and assessed for separating wall or floor systems whether in laboratories or in the field (in-situ) in attached houses and apartments.

1.2 Attached housing includes separating walls found in attached houses such as semi-detached, row (terrace) housing and apartments and separating floors as found in apartments.

1.3 At present across European countries there is a wide range of criteria which is utilised for describing the sound insulation. Whilst all countries utilise decibels (dB) for their units the *'descriptor criteria'* may include:

- $D_{nT,w}$; $D_{nT,w}+C$; $D_{nT,w}+C_{tr}$
- R'_w; R'_w+C

They may also use different frequency ranges of which the predominant low frequency limit currently is 100 Hz, with the exception of some countries such as Sweden which measure down to 50 Hz.

1.4 For over two decades there have been various discussions, papers and proposals for extending frequency ranges below 100 Hz and most commonly the discussion or proposals have suggested moving to a lower limit of 50 Hz for airborne sound insulation measurements and calculations.

1.5 More recently in the last few years the discussion to extend to lower frequencies has intensified via the draft proposals for changes to ISO 717 Part 1 via the proposed NP 16717.

1.6 The primary proposal for this extended frequency range has stemmed from experts in Germany and Austria. However, these views and recommendations have not been shared unanimously within these countries.

1.7 This paper provides a synthesis and summary of the proposals to extend to lower frequencies such as 50 Hz and the diversity of opinion, evidence and influence of such a change.

1.8 It is not the purpose of this paper to provide an alternative suggested approach for airborne sound insulation, nor to present the possibility of extending to lower frequencies for impact sound transmission. However, in reviewing other papers (out with the scope of this study) there is significant evidence to suggest extending impact sound transmission testing to include lower frequencies below 100 Hz.

1.9 This review has been funded by Eurogypsum with the purpose of providing a synthesis and also to identify the evidence or supporting rational behind the publications reviewed within this study.

1.10 The purpose of the ISO 140 and ISO 717 series of standards is to provide a common framework for the assessment of sound insulation properties of materials, systems, components and building separating elements found within buildings and the building envelope which serve as a mechanism to quantify the objective performance of such features.

1.11 Ultimately the need for such standards provide an opportunity to collectively deliver a standard approach which governments, companies, industry organisations and public bodies can utilise for the intended final objective of providing suitable privacy, quality of life and most importantly lead to the protection for building occupants by the reduction of sound transmission from neighbours.

1.12 The set criteria within each country may vary as do the minimum levels required (dB) and this is the responsibility of key government departments within each country to decide. However, irrespective of the minimum decibel level set by any country it is the descriptor criteria and frequency range embedded within ISO 717 Part 1 which provides the "keystone" on which government's incorporate within their regulations and guidance.

1.13 They also are integral to how product materials and buildings designed, built, tested and assessed towards. Thus any future core changes to the ISO 717 Part 1 have a significant impact across all countries that refer to this ISO, all companies that manufacture products and ultimately the building occupants who will live in future buildings involving the new ISO criteria.

1.14 For any changes to be made to an existing ISO it is incumbent that there should be:

i. Sufficient reasoning and evidence for such changes;

ii. Appropriate consideration to all influences and consequences (both direct and indirect);

iii. Suitable outcomes that the changes (however best intended) do not make matters worse for building occupants (particularly quality of life, privacy, health and exposure to noise) or reduce or weaken the current intended outcomes of government regulations and standards;

iv. Robust in their utilisation and do not limit or provide inflexibility over existing or current methodologies, thus reducing their range of application;

v. Provide a noticeable and defined step change of sufficient magnitude that outweighs the cost to government organisations, departments, product manufacturers, designers and acousticians of the subsequent costs incurred to change all future documents, guidance notes, product specifications and test procedures

vi. Sufficient (majority) agreement across the experts and member countries participating and that all evidence has been ‘impartially’ reviewed, discussed, qualified and quantified which provides a suitable majority decision which is defendable, rational and leads to an outcome which provides a positive contribution to society and our future generations.

1.15 The synthesis within this report will in part reflect on the aspects (i-vi) of 1.14 when discussing some of the papers which have been reviewed.

1.16 The paper is divided primarily in key sections involving:

- Why simplify ISO 717 Part 1?
- Extending to lower frequencies;
- Uncertainty;
- Subjective listening test and real buildings;
- Influence on constructions, products and statutory guidance;
- Influence and limitations of build dimensions; and
- The future options.

2.0 Why simplify ISO 717 Part 1

2.1 The current rating of airborne sound insulation is provided by the "descriptor" criteria set out in ISO 717 Part 1. Scholl et al [3] provided proposals of how a simplification of the current descriptors could lead to a new single number descriptor involving R_{living}. The rationale behind such a descriptor is it would provide for a more simplified approach, by reducing the number of descriptors and at the same extend the airborne sound insulation frequency test range from 50 Hz to 5000 Hz.

2.2 Scholl et al indicated that such a new system would require the single number quantity:

- To correspond to human perception of noise;
- Should be of the same type such that it is evaluated according to the same type of mathematical procedure;
- The physical and psycho-acoustic background should be clearly visible;
- The names should be as simple as possible; and
- The number of single number quantities should be as small as possible.

2.3 The proposal involved the new single number quantities being based on A-weighted sound levels or A-weighted sound level differences.

2.4 Scholl et al also outlined that for the purposes of testing on-site these could be reported as sound pressure level differences using the descriptor D (D_n for normalised to standard absorption areas in the receiving room, or, D_T normalised to reverberation times in the receiving room). There was also the suggestion that it may be possible to keep only one of them in future.

2.5 Such clarity between laboratory and field measurements would be helpful and with a potential further simplification of only using one in future this would be a positive step forward to reduce the number of descriptors and criteria.

2.6 A significant reason behind why simplification of ISO 717 is required, was outlined by Rasmussen and Rindel [4] where a wide range of airborne sound insulation descriptors where found to be used across Europe. This was further highlighted in the EU COST Action program TU0901 and summarised in Chapter 2 [5] by Rasmussen and Machimbarrena within the COST Action publication "*Towards a common framework in buildings acoustics throughout Europe*".

It was identified that there were at least 7 different airborne descriptor criteria and in addition a range of variations and recommendations depending on different limitations set within national standards.

Airborne sound	
No. of countries	Descriptor
16	R'_w
3	$R'_w + C$
1	$R'_w + C_{50\text{-}3150}$
6	$D_{nT,w}$
2	$D_{nT,w} + C$
1	$D_{nT,A}$ ($\approx D_{nT,w} + C$)
1	$D_{nT,w} + C_{tr}$

Figure 2.6 – Airborne sound insulation descriptors applied for regulatory requirements in European countries [5].

2.7 It was also noted that even using the same descriptor criteria e.g. $D_{nT,w}$ there was a variation on the minimum national requirements between countries of up to 10 dB. Both Austria and Scotland had the strictest airborne sound insulation criteria for multi-storey and row housing.

2.8 Scholl et al [3] provided good arguments as to the rationale behind a more simplified approach to ISO 717-1 and this was also a key feature and objective behind the COST Action TU0901. *Scholl et al* also indicated that simplification of single number quantities can limit their applicability and they "*fit only best for the situation which was underlying their definition*" and "*in every other case they are a compromise*". Scholl [6] later summarised the scope and resolution behind the planned revision for ISO 717 and the potential for one criterion R_{living} to be a 'catch all' for airborne sound insulation which was equivalent to $R_w + C_{50-5000}$.

2.9 The outline proposal for the revision of ISO 717 included simplification of and suggested descriptors summarised [6] for:

i. Airborne sound insulation R_{living}

ii. Road traffic noise $R_{traffic}$

iii. Speech intelligibility R_{speech}

iv. Impact sound transmission R_{impact}

A key output from the proposals for airborne sound insulation was the benefit of linking the new named descriptors to existing descriptor criteria within the current ISO 717-1. This would allow "*further applicability of existing test reports as a high priority*" [6].

The proposed changes [6] as a collective would be the largest and most significant change to building acoustics descriptors ever proposed and:

- also have key aims of simplifying declarations of performance and have "*new names*" of the selected quantities which were "*self-explanatory as possible*" [6].

- The revision of ISO 717 would also be given a new number ISO 16717 and this would provide an "*opportunity to adjust requirements and improve buildings and building elements appropriately*" [6].

- "*Changes here, however, would imply the abandonment of existing single number quantities*" [6].

There is clearly merit in the proposals via the names being more self-explanatory, the potential to improve buildings and building elements and start afresh with clear changes that would be utilised (as standard) across so many countries.

It would no doubt also reduce the complexity for some companies when testing, training their staff, working in different countries and developing marketing literature that a simpler approach would be more transferable.

However, this could also be done by using only one or two of the existing criteria within ISO 717-1, if there was common agreement. Also if the set descriptor criteria (or new adjusted criteria chosen) was able to take account of the majority of noise transmission types then it would lead to an improvement overall in functionality of addressing optimally a sufficient range of frequencies.

3.0 Extending to lower frequencies

3.1 Extending to lower frequencies within this report is in relation to including frequencies below 100 Hz to a minimum limit of 50 Hz. This report does not include the issues of speech intelligibility in relation to internal walls and partitions as found in housing and offices. The focus of this report is primarily in relation to airborne sound insulation of separating (or party) walls and floors as found in attached houses and apartments.

3.2 Of the 35 countries participating within the COST Action TU0901 only one country (Sweden) specifically extended to lower frequencies [5] for airborne sound insulation within national standards.

3.3 A particular statement which appears in [6] states "*recent investigations had shown that for a good correlation between single number quantity and human perception, the inclusion of frequencies below 100Hz is essential*". Although no specific papers are then cited as part of this statement the paper continues to then describe and cross refer to Scholl et al [3] and Mortensen [7].

Mortenson [7] undertook a laboratory based study involving 25 participants to investigate a range of typical living sounds with the sound insulation involving a range of construction types including heavy and lightweight constructions. However, the actual sound insulation across different lightweight and heavy weight constructions were then "shaped" as shown below. These shaped results were then utilised for the subjective tests undertaken and termed:

- Light;
- Light-med;
- Medium;
- Med-heavy; and
- Heavy.

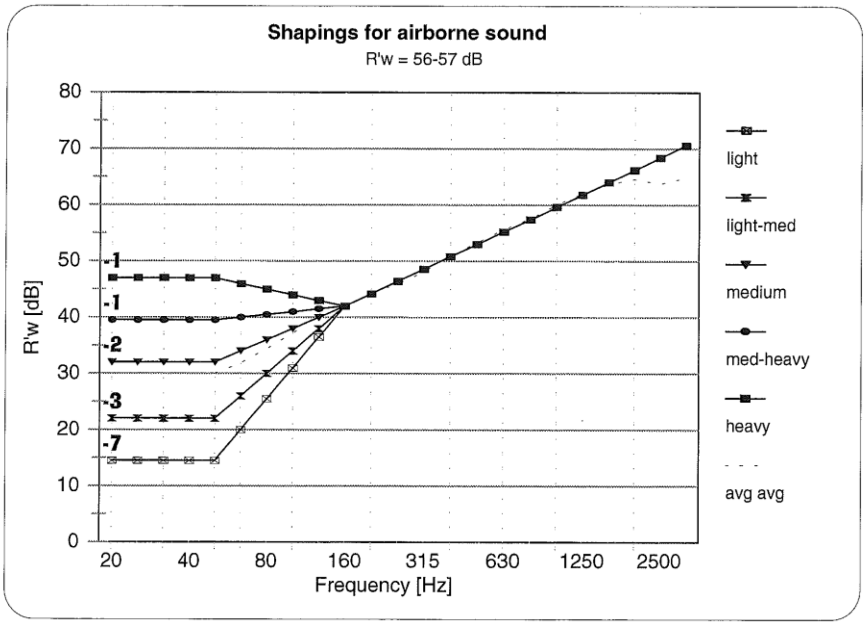


Figure 3.3A - Mortensen's 'shapings' for airborne sound insulation for different types of constructions. Next to every curve the C-correction value is listed.

In most real constructions at low frequencies, whether heavy or lightweight there are resonant and non-resonant (forced motion) dips in performance at specific frequencies. There will be higher and lower levels of insulation at specific third octave frequency bands. The 'shapings' utilised by Mortensen did not reflect this type of behaviour for lower frequencies and it may be argued by some that it is slightly misleading to then name or identify such 'shapings' as light, heavy etc..

The study [7] found that noise transmitted through light constructions is rated more annoying than noise transmitted through heavy constructions. The difference related to the lower frequency content in noise transmitted through lightweight constructions. Interestingly the report also found that 80% of the subjects are annoyed for "*any type of construction*".

However, the importance of looking at such variation at low frequencies and its effect on subjective listening tests is still very useful, but the applicability of stating a direct correlation for lightweight constructions as being more annoying using a flattened "shaped" level is questionable.

It would be expected given the significant 'stepped difference' in the flattened shaped curves that the lower shaped curves (light, light-med) would be subjectively worse. Furthermore it could also be argued that these are not replicable to typical field sound insulation performance of lightweight constructions which often outperform heavyweight constructions at mid and high frequencies which was not included in this study. Furthermore Mortenson showed the typical performance for lightweight and heavyweight constructions for a range of frequencies and when assimilated on the Mortensen's "shaped" classifications of lightweight to heavyweight constructions it can be seen that the "shapings" over emphasise (poorer) the lightweight classifications considerably and the heavy classifications (better).

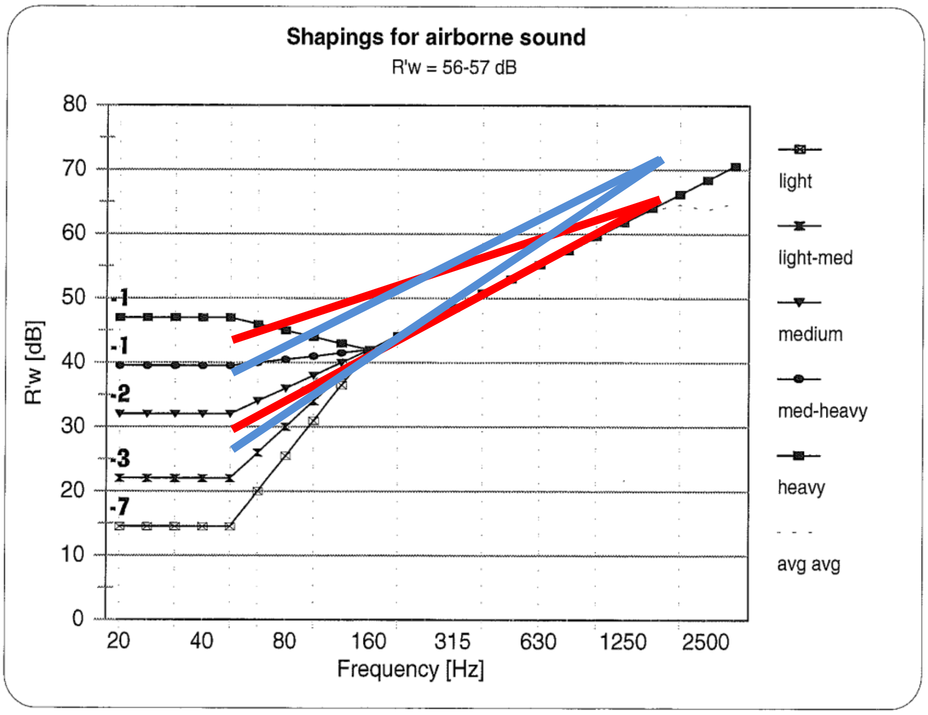


*Figure 3.3B – Superimposing the outer boundaries of the presented [7] measured **Heavy** and **Light** constructions for low and medium frequencies over the categorised construction weight 'shapings'[7].*

The Mortensen study is useful for focused examination of low frequency variations on subjective responses of influence on annoyance and concentration and its interesting findings of 1.2% more annoyed per dB (A) increase. However, it cannot be directly linked to the type of construction without utilising actual frequency performance of both heavy and lightweight over the full frequency range. Also the use of actual 'real' datasets for heavy and light constructions for listeners would then have allowed a more direct comparison of subjective response to actual 'heavy *or* light' construction.

A specific important finding also found by Mortensen was "*experiments have shown than an increase in the level at low frequencies produces a higher level of annoyance, <u>though not as much as an increase in the general level</u> (for all frequencies) produced*". This underlines the potential importance of looking at all frequencies holistically 'in the round' when setting descriptor criteria to reduce annoyance and will be discussed later in this report.

3.4 Other papers which have studied in-depth the variety of descriptors, criteria, frequency ranges and diverse sound sources have been written by Park and Bradley [8]. Their detailed findings demonstrated the complexity of trying to fit one descriptor that can suitably reflect the required weighting of different sources of noise. A key finding was the scenario that two distinct descriptors may be required for dealing with music noise and normal living noise such as speech. They found high correlations when utilising specific separate descriptors for each of these two sound sources. They also suggested that the use of a compromise descriptor approach to include both speech and music may lead to "*less accurate predictions of some responses*".

This concurs with previous studies by Smith *et al* [9] which outlined the difficulties of placing stronger emphasis on lower frequencies using spectrum adaptation term C_{tr}, as found in sound insulation building standards in England and Wales. The paper outlined that to serve both mid and high frequencies and low frequencies for sound insulation there may be the need for designing to "two masters" of $D_{nT,w}$ and $D_{nT,w}+C_{tr}$, so as not to only focus on low frequencies and avoid creating issues at mid and higher frequencies. But this can be difficult to enact into standards as dual targets can create confusion for designers and reporting of in-situ results. However, it could be argued that acoustic designers already have dual targets for separating floors via airborne and impact criteria.

3.5 Some of the key drivers for extending building standards to include lower frequencies are the change in living habits and residents listening to music from hi-fi appliances and loudspeakers systems. This formed the background to the study by Lang and Muellner [10] who undertook a survey to review the time of day and the time duration people were listening to such music in their home with different types of modern equipment. Just over a quarter of residents listened often to music at home with over 16% never or seldom reducing the loudness level of music after 10pm.

3.6 In some countries to reduce such incidents of anti-social behaviour, where loud music is being played by residents in adjoining premises, such equipment can be seized by the police or noise enforcement officer. In more serious cases residents can be charged with a criminal offence, such as in the UK under the Anti-social Behaviour Act.

3.7 Whilst there may be anti-social behaviour laws in some countries the recommendations by Lang and Muellner stated that "*music, particularly rock and pop is an important sound source in residential buildings. Such music has a mainly linear frequency response down to the third octave bands 50, 63 and 80 Hz and that this should be taken into account by the new draft of ISO 16717*".

3.8 Adnadevic *et al* [11] and Masovic *et al* [12] demonstrated the significant range of sounds which are present within normal living environment within dwellings. Thus any focus on specific frequencies or weighting towards specific frequencies through a single descriptor may create further issues in less-weighted frequencies. This has been one of the issues facing England and Wales where a stronger emphasis was placed on lower frequencies [13] to deal with low frequency music and hi-fi sound systems, which led to a reduced influence on mid and higher frequencies. This is discussed in more detail in Section 6 of this report.

3.9 It is also of interest to note that one of the most cited papers in relation to the influence of low frequencies and annoyance is the paper by Rindel in 2003 [14] and is strongly linked to a summary of Mortensen's [7] research findings.

3.10 There is a specific shortage of papers in the subject area involving the analysis of subjective findings of building occupants and low frequencies for airborne sound insulation. This was also the case in the ISO change proposal papers where there was a lack of referenced papers to demonstrate or evidence the critical support for extending low frequencies for airborne sound insulation.

3.11 However, on the contrary there are a wide range of published reports and papers in relation to impact sound transmission and low frequencies where a range of tests have been undertaken involving diverse testing techniques and different floor constructions. Considering the availability of so many studies on low frequencies and impact sound transmission it is surprising that the ISO standard has not already been amended to include or deal with such issues.

3.12 The more recent research studies which are recording the types of noise and frequency content [10, 11, 12, 15] are useful in identifying the current living environment for housing occupants. These publications, building on previous work by Rindel [14] and others, raise an important issue that ISO standards should be relevant to current needs.

3.13 A recent paper by Ryu and Joen [16] demonstrated the increase in sensitivity towards indoor noise as opposed to outdoor noise for housing occupants. Although no correlation with frequency was reported the types of noise sources adopted in the study for indoor noise involving both airborne and impact would also have involved wider frequency ranges below 100 Hz.

4.0 Uncertainty

4.1 Uncertainties are mainly caused by the modal behaviour of the airborne and structure-borne sound fields.

4.2 When products or wall or floor systems are specified for future buildings the designers (whether architect, product manufacturer or acoustician) will have a certain degree of confidence in the design and resultant performance achieved.

4.3 Extending the frequency range for airborne sound insulation to lower frequencies can also influence the uncertainty of single number quantities (SNQs). Scholl et al [3] stated that the uncertainties below 100Hz will always be larger than at medium frequencies around 500Hz.

4.4 Mahn and Pearce [17] demonstrated that the extension to the frequency range had a significant influence on the uncertainty for lighter weight constructions. Their findings included that in some cases the uncertainty doubled, in 98% of the assessed light weight constructions the uncertainty increased and the maximum uncertainty changed from 2.9 dB to 4.6 dB. A specific example to demonstrate the influence of uncertainty for a manufacturer was provided in their paper [17]:

> **Using existing frequency range 100 Hz to 3150 Hz** a wall had a laboratory performance value of 54 dB with an uncertainty value of 2.6 dB. Taking into an account a wider uncertainty of being tested in other laboratories the uncertainty value would increase to 5.1 dB and so the declared sound insulation for the wall would be 48.9 dB
>
> **Using the extended frequency range of 50 Hz to 5000 Hz** a wall had a laboratory performance value of 49.1 dB with an uncertainty of 4.6 dB. Taking into an account a wider uncertainty of being tested in other laboratories the uncertainty value would increase to 9.0 dB and so the declared sound insulation for the wall would be 40.1 dB.

The above is a useful indicator of the "*uncertainty budget which would be costly to the manufacturer or builder*" [17].

4.5 Hongisto *et al* [18] also raised concerns regarding the uncertainty and reproducibility of extending the frequency ranges for airborne sound insulation. They found that the reproducibility was increased (i.e. larger uncertainty) when inclusion of measurement data below 100 Hz was included.

4.6 Monteiro *et al* [19] discussed the comparison of uncertainty when extending low frequencies for both heavy and lightweight separating walls based on field data. Their findings found an increase in uncertainty for both heavy and lightweight walls when extending the frequency range. There was a more significant increase in uncertainty for lightweight construction walls. They indicated that the future uncertainty influence must be considered and stated when delivering reports on sound insulation performance for verifying compliance with legal building requirements when extending the frequency range. They also demonstrated the lack of reverberation times (non-measurable) as a percentage across 20,000 datasets for frequencies involving 50 Hz, 63 Hz and 80 Hz, as shown in Figure 4.6 below.

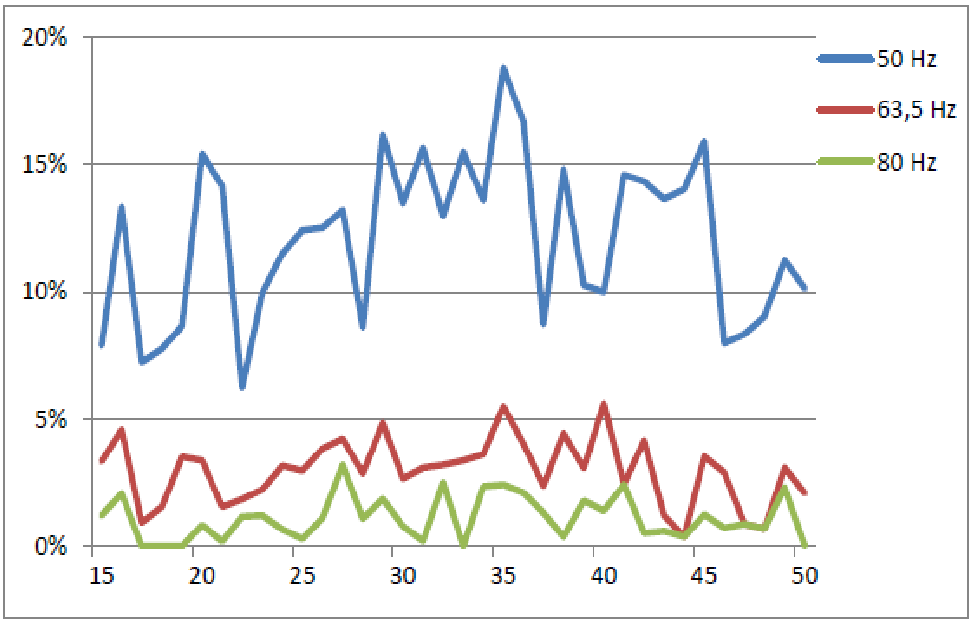


Figure 4.6 – Percentage of lack of reverberation time measurements (non measureable) for 50 Hz, 63 Hz and 80 Hz from field tests (in-situ) [19].

5.0 Subjective 'listening' tests and real buildings

5.1 Any required changes to ISO airborne sound insulation criteria and descriptors must ultimately be of use to the final building occupant (the 'un-wanting' listener). Some research papers have carried out listening tests to ascertain annoyance factors or disturbance felt by the listeners from pre-recorded sounds and pre-recorded sound insulation influenced sounds (where sounds are altered to simulate the "real" or in-situ sound insulation properties of different walls or floors).

5.2 One of the key positive outcomes of the papers by Scholl *et al* [3] has been the stimulus for many researchers to look more closely at airborne sound insulation criteria, low frequencies, influences, variations, limitations and subjective feedback from listening tests. Listening tests have also been one of the new work packages of research initiated by the Department of Communities and Local Government for England in their current review (2013-14) of the building regulations for new housing Part E – 'resistance to the passage of sound'. The inclusion of listening tests within the government study stemmed from the discussions and ongoing research in other countries which was being reported through COST Action TU0901.

5.3 The previous study evidence utilised to suggest the need to extend the airborne sound insulation frequency range [3] has in various papers been strongly linked with Mortensen's paper [7] and perceived problems with lightweight constructions. Whilst useful to look at artificial step changes of sound insulation at low frequencies, as previously mentioned in this report and also highlighted by Hongisto *et al* [18], Mortensen's paper [7] did not prove that significant perception differences occur with light and heavy weight structures.

5.4 A study by Rychtarikova et al [20] highlighted the need to consider the whole sound insulation frequency performance of a wall when comparing different lightweight and heavyweight constructions. Using 64 different typical living noise stimuli which were then filtered through two different wall transmission spectra involving lightweight and heavyweight walls as shown in Figure 5.4. Both walls had the same single value rating (51 dB) when calculated for R_{living} involving the extended frequency range. The R_w of the lightweight wall was 69 dB and the R_w of the heavyweight wall was 52 dB.

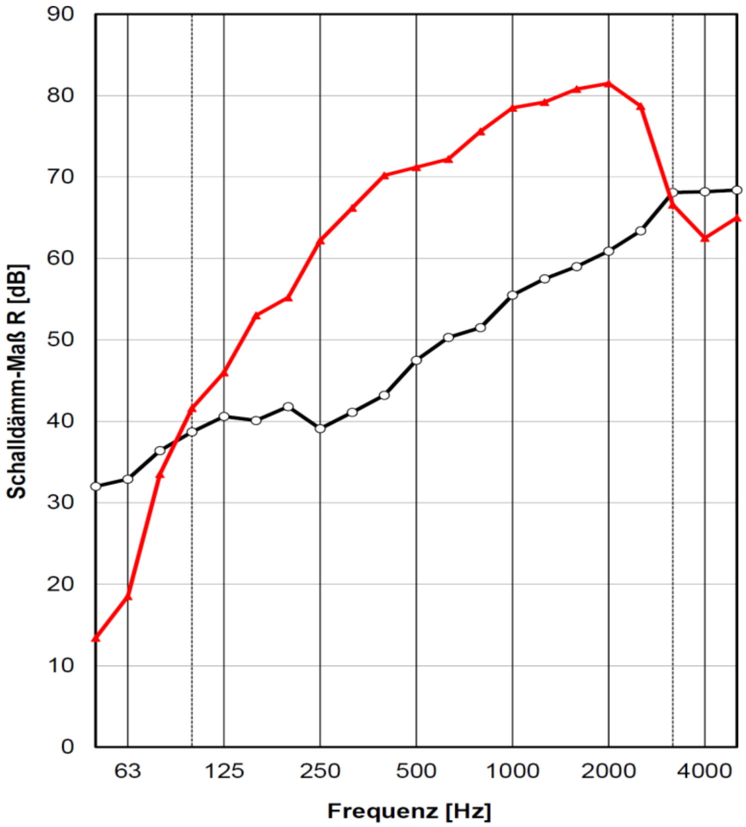


Figure 5.4(a) - Sound reduction index R (dB) for the two walls used during the listening tests [20]. (Red line is the lightweight wall; black line is the heavyweight wall).

When the listeners (40 in total) were asked which sound was perceived as louder (not knowing what was the wall type) most of the listening subjects perceived the masonry wall as louder. Only a few times did the listener perceive the lightweight wall as louder and this occurred where music or a film was amplified by the neighbours home cinema or powerful hi-fi system with large amounts of deep bass sound. This was visually presented by the authors as shown in Table 5.4.

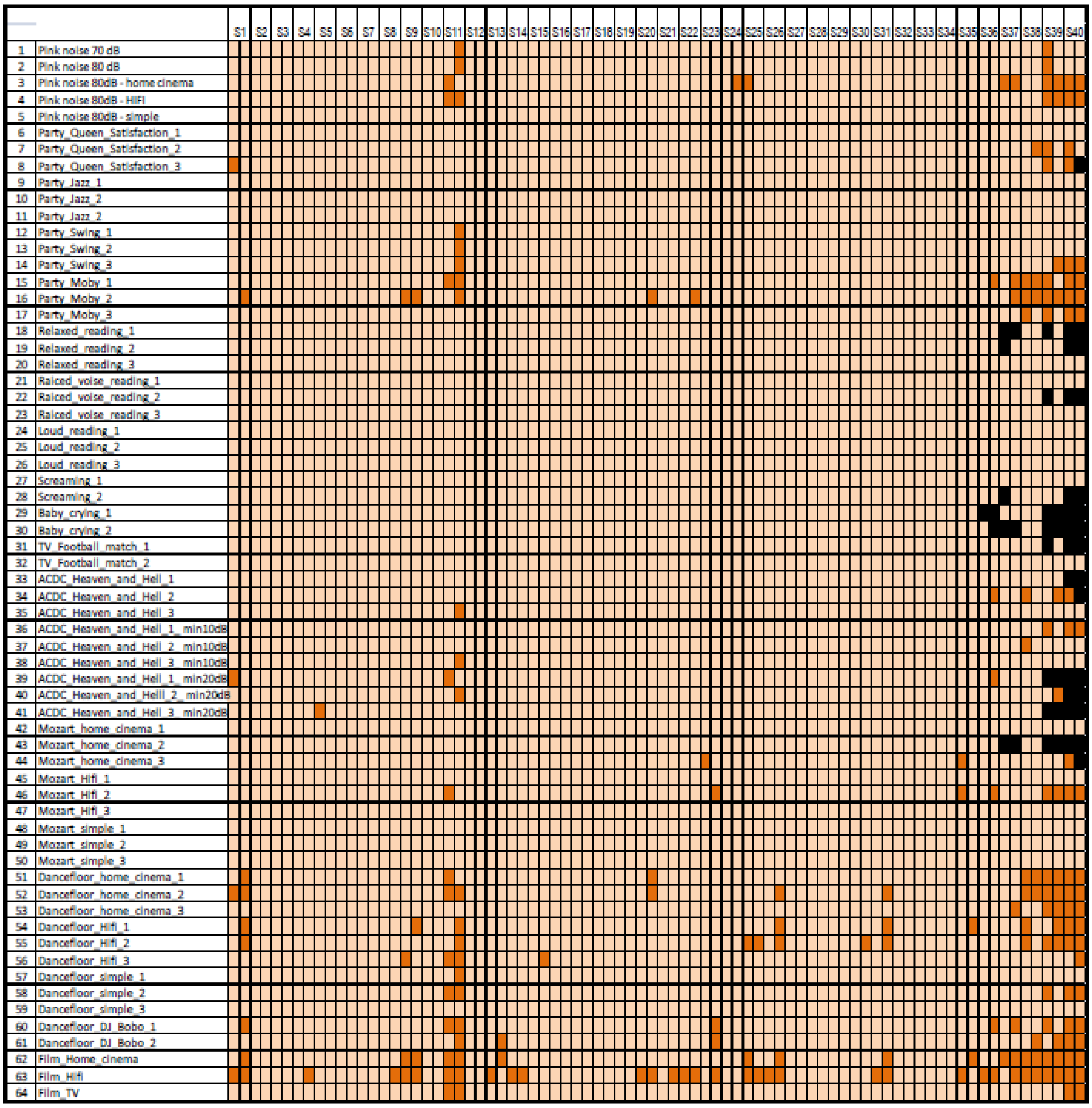


Figure 5.4(b) – Light orange colour boxes represent cases in which sound transmitted through the masonry wall was heard as louder. Dark orange boxes depict cases that correspond with the lightweight wall having a weaker sound insulation. Black squares refer to cases in which a subject did not hear the sound.

5.5 A second series of tests was also undertaken [20] where the level in the listener's headphones was increased by 30 dB. Some of the sound stimuli were on average heard almost equally loud for both walls. Although this second series of tests was performed on only 12 listeners the responses support the trend given by the Equal Loudness contours (i.e. low frequencies are perceived less loud at low intensities than at higher sound intensities). In addition, in real buildings there is often an additional background ambient noise (often found in urban environments) which can also serve as 'masking noise'.

5.6 The study by Rychtarikova *et al* [20] found that there was an overestimation of the importance of low frequencies in previous proposals to extend the airborne sound insulation requirements.

5.7 Masovic *et al* [21] reviewed the suitability of the proposed ISO 16717-1 (R_{living}) spectra for rating airborne sound insulation and found that whilst addressing music with strong bass content it overestimates noise levels at low frequencies.

5.8 Hongisto *et al* [22] investigated disturbance caused by airborne living sounds heard through walls via a laboratory experiment. The study involved 26 subjects evaluating the disturbance caused by 54 sounds covering 9 different wall types. They found that R_{w} (using minimum 100 Hz) provided a better prediction or assessment criteria than R_{living} (using minimum 50 Hz). Only in the case of very bass-rich music did R_{living} predict disturbance better than R_{w}.

5.9 Field studies have also been undertaken where occupants have been asked about their acoustic or sound insulation satisfaction. Smith *et al* [23] undertook a large set of studies involving over 300 residential occupants and measured the sound insulation properties of separating walls and floors. Neighbouring occupants were interviewed in their homes at the adjacent properties to the separating wall or floor. The apartments tested involved masonry walls, concrete floors and timber floors. Despite the presence of low levels of sound insulation performance at lower frequencies the main concern by occupants was disturbance from people talking and sound from televisions (both specifically related to masonry walls). The one key area of concern relating to low frequencies reported by the occupants was impact performance and the sound of footfall noise.

5.10 Hongisto *et al* [24] undertook field surveys involving 597 participants where they were asked to complete a series of questions relating to acoustic satisfaction. The building types chosen reflected different periods of build and regulations and the findings suggested that there did not appear to be any particular reason to improve the building code regarding future new buildings (i.e. no requirement to extend the frequency range in future).

5.11 The Scottish Building Standards Division study [25] reviewed the sound insulation performance requirements for their building code Section 5: Noise during 2008-09. As a result of the review of the research and responses during the government consultation it was decided not to extend the frequency range but instead increase the $D_{nT,w}$ minimum performance level which would increase overall sound insulation including low frequencies. It is interesting to note that Scotland annually builds the highest proportion of lightweight buildings in Europe (greater than 70%) of new housing. There is a growing consensus across acoustic experts that in future there may be a need to extend to lower frequencies for impact sound transmission (footfall noise). Yet there is not a requirement or identified need to extend sound insulation frequencies below 100Hz for airborne sound despite the extensive use of lightweight timber frame attached housing.

6.0 Influence on constructions, products and statutory guidance

6.1 When extending the frequency range the reported performance of constructions can change and for some constructions, particularly lightweight, this can be quite significant.

6.2 Wittstock [26] illustrated the influence on the potential standard deviation across diverse constructions types. In most cases the influence was low but for lightweight constructions the standard deviation could almost double.

6.3 In terms of the change to a reported construction performance, the extension of the frequency range to include lower frequencies can dramatically alter the reported performance value.

6.4 In 2012 Monteiro *et al* [27, 28] analysed substantial field data to review the influence of extending the frequency range for heavy and lightweight constructions. They showed that under the proposed new criteria [3] where walls had similar values in performance their current reported values in terms of $D_{nT,w}$ could vary by 8 dB.

They also illustrated the variation at each third octave band below 100Hz (for example walls) and how the proposed new criteria would inadequately report this variation. In addition they stated that the proposed criteria [3] for a future ISO 16717 would not be the optimum approach for a future ISO standard.

6.5 Rychtarikova *et al* [29] in their presentation at Internoise 2013 illustrated 5 pairs of walls with similar performance values when including low frequencies using the R_{living} [3] approach, as shown in Figure 6.5.

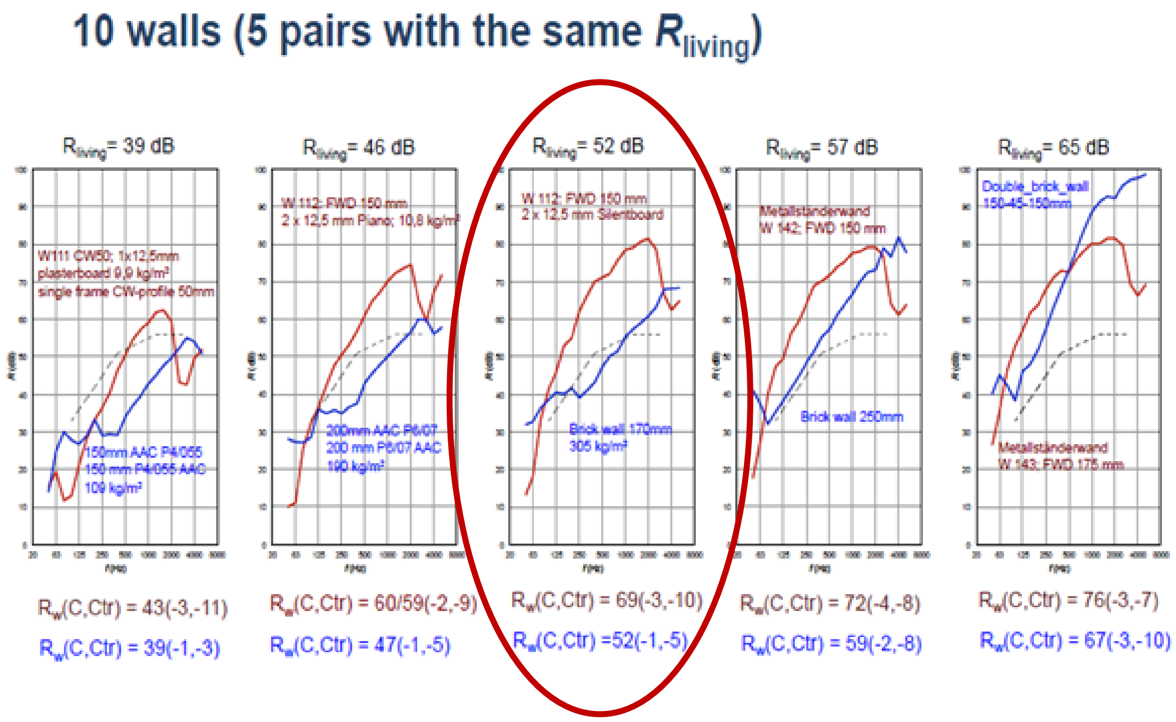


Figure 6.5 – Five pairs of walls with the same R_{living} [29].

As can be seen above very low sound insulation performance at 50 Hz and 63 Hz could entirely control the reported performance value. Thus two walls (circled) under current ISO criteria standards R_w are reported as 52 dB and 69 dB (17 dB difference) but under the proposed new criteria would be reported as the same value of 52 dB using R_{living}.

6.6 Rumler and Seidel [30] also demonstrated a similar anomaly when including low frequencies as proposed by Scholl et al [3]. They compared two walls and demonstrated the effective loss of reporting at mid and high frequencies which are important to protect against sound transmission such as speech and other common living noises.

6.7 What is quite apparent from the referenced papers [20, 21, 22, 27, 28, 29, 30] is the concern relating to the under reporting of mid and high frequencies by the methodology proposed and over emphasis placed on lower frequencies. Such that current high performing walls and floors for sound insulation, where there is no issue of complaints being reported or cited, would be penalised under the proposals. The strong focus on low frequencies, due to the methodologies proposed, creates an imbalance in the reporting on the ‘real or actual’ effective sound insulation which deals with the majority of standard living noises.

6.8 This leads to the future issues that product companies could focus their design attention on only a few low frequencies (for some bass music) and still achieve good low frequency performance but significantly reduce the potential sound insulation for mid and high frequencies. This may lead to a reduction in effective sound insulation for normal living sounds in future buildings built under such proposals.

6.9 Mid and high frequency sound insulation is important to protect the privacy of occupants. An example of where one country has already faced such a dilemma is England. In 2003 the inclusion of spectrum adaptation term C_{tr} was to improve sound insulation against low frequency noise sources such as from music hi-fi. Although they opted to remain at 100 Hz for the minimum frequency the influence of the strong focus by C_{tr} on 100 Hz led to some heavy walls being able to pass the standards but with poor performance at mid frequencies [31]. Thus some walls would now pass that previously had failed and other walls which failed would now pass.

Due to the majority of the house building industry adopting Robust Details approach, which set a higher design target of 5 dB above the regulatory minimum and also ‘by design’ of high performing walls for low, mid and high frequencies the potential number of complaints was reduced. Since the introduction of Robust Details the recorded number of noise complaints for new housing in England and Wales reduced four fold over the subsequent period 2004-2009.

6.10 The above focus on lower frequencies by using C_{tr}, but setting a high overall performance target, has achieved good levels of sound insulation and significant reduction in complaints. This indicates that if the minimum target airborne performance is sufficiently high this may avoid some of the issues or difficulties of poorer performance at mid and high frequencies not becoming a factor.

6.11 Given that Sweden already extends the frequency range to 50Hz and there does not appear to be any major reporting of issues does this lead to a question of:

"If low frequencies are included and the target regulatory minimum airborne sound insulation is sufficiently high (as found in Sweden) does this remove some of the previous discussed concerns and factors relating to including low frequencies?"

6.12 Therefore by default, have England and Wales (by placing greater emphasis on lower frequencies 100Hz to 160Hz by using C_{tr}, not extending to include low frequencies and setting a sufficiently high robust detail design target) delivered similar outcomes to Sweden (where they did extend to include low frequencies to 50Hz and had a sufficiently high airborne design minimum target)? This is worthy of further research.

6.13 This also leads to a further question. If countries are planning to extend the airborne sound insulation frequency range but the minimum airborne target is not sufficiently high – then it is possible that future issues will occur with mid and high frequencies. This is part of the ongoing review into Part E building regulations for England "resistance to the passage of sound" whereby one or two (not often used) constructions which just meet the minimum target regulatory performance (i.e. are 5dB below the higher performance Robust Detail target) and have issues with mid and high frequency living sounds transmitting between dwellings.

6.14 This creates a conundrum for some EU countries, when extending to include lower frequencies, as they will need '*to strike the correct balance'* of setting the minimum airborne sound insulation standard under this new criteria to sufficiently deal with low frequencies and also with mid and high frequencies. Will setting the minimum target require a +5dB improvement beyond current targets in EU countries with low levels of airborne performance factors? Each EU country would have to undertake a regulatory impact assessment to identify if it is justified on the industry particularly if there is not a clear evidence base of airborne noise complaints at low frequencies (excluding anti-social behaviour).

6.15 If the above is correct, then quite a few EU countries if they adopt such a new criteria (which currently have low airborne minimum requirements) will have to significantly increase their overall minimum airborne sound insulation requirements to avoid complaints occurring due to sound transmission (and on-site sound tests passing) where speech and normal living noises will be heard.

6.16 Major future changes in reporting of the performance of sound insulation by introducing new wider frequency ranges could possibly lead to significant confusion for the sector, designers, product manufacturers and also in the assessment of products and systems [32].

6.17 A key output from the proposals to alter the airborne sound insulation was the benefit of linking the new named descriptors to existing data criteria within the current ISO 717-1. This would allow "*further applicability of existing test reports as a high priority*" [6].

"*Further applicability of existing test data*" however would only be the case where the existing test data reports were tested with appropriate valid measurement standards and recorded the extended lower frequency ranges.

This was also pointed out by Scholl et al [3]. However, the key aspect is a large majority of existing constructions, products and systems do not have such data with extended frequency ranges, specifically field (on-site) data.

The introduction of new descriptors and ranges, if existing recorded data was not sufficient, would require:

- governments to identify the influence and implications of such changes on current and mature national building standards, which would utilise this new descriptor and extended frequency range;

- governments to assess the influence on current construction types and systems which they may currently describe in government guidance documents showing suitable constructions which meet the criteria;

- governments to assess the performance of different core constructions lightweight and heavyweight. This would be required to ensure they are not adversely affecting one core (industry sector) construction over another, without suitable evidence to explain the adverse effect on health or quality of life supplied by the current guidance constructions;

- product manufacturers to assess the implications and influence on their products and also within system constructions involving multiple elements;

- product and industry sector bodies to undertake significant laboratory and field (on-site) testing for future new technical literature and marketing information.

7.0 Influence and Limitations of Build Dimensions

7.1 A number of papers have cited various issues with extending low frequencies to 50Hz. Some of the physical attributes of testing in real buildings involve room size limitations and the effective generation of acoustic modes and wavelengths.

7.2 Osipov et al [33] demonstrated that, when determined by the pressure method, the sound transmission at low frequencies (below 315Hz) depends not only on the property of the test wall but also on the geometry and the dimensions of the room-wall-room system.

7.3 As Scholl et al [3] indicated there are special sampling techniques as demonstrated by Hopkins and Turner [34] which could reduce the uncertainties. However, for on-site testing for pre-completion regulatory compliance in some countries the time and access to sites is already restrictive and adding additional tests may not be conducive to site operations and may lead to additional costs.

7.4 Osipov et al [35] also undertook measurements in test rooms with volumes of $85m^3$. This was utilising measurements undertaken in laboratories and demonstrated for prediction models, even with such room volumes, that *"variation in low frequency sound insulation compromises the accuracy of the predicted sound insulation in-situ"*.

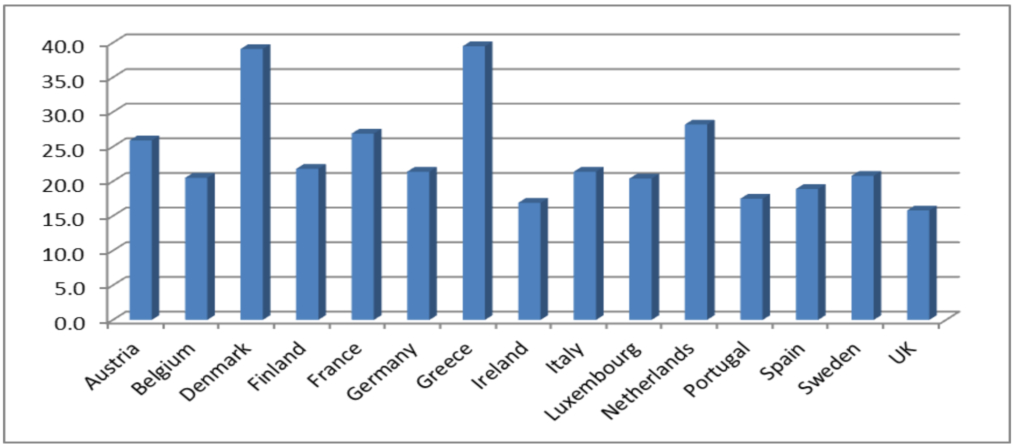
7.5 Given that many typical room sizes across Europe are smaller than $85m^3$ this would also cause future difficulties for designers who depend on prediction analysis designs if the frequency range was lowered to 50Hz.

7.6 This also leads to how some countries may review future incorporation of extending to lower frequencies from an amended ISO within their building regulations or standards for sound insulation.

7.7 Table 7.5 shows the relative square metre area for new homes in a range of countries. The UK has some of the smallest room sizes with Greece and Denmark having some of the largest, as shown below in Figure 7.7.

Newly built dwellings			
COUNTRY	**floor space, m²**	**number of rooms**	**room size, m²**
Denmark	137.0	3.5	39.1
Austria	96.0	3.7	25.9
Netherlands	115.5	4.1	28.2
Luxembourg	104.1	5.1	20.4
France	112.8	4.5	26.9
Italy	81.5	3.8	21.4
Finland	87.1	4.0	21.8
Sweden	83.0	4.0	20.8
Greece	126.4	3.2	39.5
Belgium	119.0	5.8	20.5
Germany	109.2	5.1	21.4
Portugal	82.2	4.7	17.5
Spain	96.6	5.1	18.9
Ireland	87.7	5.2	16.9
UK	76.0	4.8	15.8

Figure 7.7 – Typical overall floor space and average room sizes (graphed below) found in some EU countries [36].



7.8 Another aspect to consider is the room height. Room heights for example in some EU new build housing are typically 2.4m to 2.7m but can be higher. As such 'average room area' and 'room height' of new build housing and their restriction on the modal behaviour in each country will be important aspects as to the efficacy and functionality of adoption (or not) of extending low frequencies from 100Hz to 50Hz within their building standards and regulations.

7.9 The effective separating wall area between attached houses and flats is another factor to consider. Whilst laboratories may test for wall areas of 10-15m^2 in real housing these can be much smaller. The reduced separating wall areas further reduce formation of sufficient modal behaviour within the structure and modal coupling. Scholl *et al* [3] also referred to the increase in uncertainties at lower frequencies due to the modal behaviour of such sound fields.

7.10 There are various factors in other papers and evidence to suggest that extension of low frequencies for impact sound insulation for footfall noise are relevant, although this is not the focus of this summary paper.

7.11 Whilst theoretical and measured data show airborne mass-spring-mass resonances below 100Hz due to various constructions there is little evidence to suggest this correlates with complaints. In fact there is more evidence to reflect the importance of dealing with mid and high frequencies correctly to ensure higher performance, quality of life and privacy needs are met.

8.0 Future

8.1 As shown by the COST Action final conference paper by Rychtarikova [37] the hearing range of 1,300 tones is almost wider than the visual cortex and hues of colour humans can perceive. In effect the dynamic range of hearing is wider than that of sight. The previous papers mentioned in this report which have cited various types and sources of noise commonly found in residential housing illustrates the diversity and complexity of what ISO 717 or future revised ISO has to address.

Many authors have stated within their papers the need to involve low frequencies within future sound insulation standards. However, what is commonly repeated in many papers is that the proposed R_{living} or R_{w}+C $_{(50\text{-}5000\text{Hz})}$ or D_{nTw}+C $_{(50\text{-}5000\text{Hz})}$ may not be sufficient to fully represent and appropriately weight the typical living noise spectrum occupants experience.

Furthermore as stated by Demanet and Houvenaghel [38] to define a new objective rating for sound insulation at low frequencies requires to "*study all the aspects*". They like others have outlined the threat of increasing low frequency sound reduction and neglecting sound reduction achieved at higher frequencies.

8.2 Sweden has utilised low frequencies within their building regulations for some years. But many other country governments and experts believe this requires more time to be investigated before they apply this to their standards in future, or in some cases where research has been undertaken, there is not sufficient evidence to extend to lower frequencies..

8.3 Detailed research incorporating build styles, room sizes and the functionality of applying low frequency sound insulation testing on real sites, in countries with mandatory sound insulation testing has not yet been undertaken.

8.4 The UK has mandatory sound insulation testing and currently has the largest on-site (in-situ) sound insulation database of any EU country and has shown some of the issues and complexities which may occur [Monterio, Smith]. Scotland which has the highest proportion of new build lightweight buildings has opted to raise the overall $D_{nT,w}$ target performance value and remain at 100 Hz.

8.5 Countries generally only wish to change their regulatory criteria where there is an evidence based approach which can justify such an alteration. Whilst there are numerous papers found by the author on low frequency sound transmission problems, complaints and annoyance factors for impact sound transmission there is an almost an absence of complaints relating to airborne sound insulation at low frequencies. The issues which are related to this factor are bass music and hi-fi systems.

8.6 As Lang [10] and other's papers have indicated bass music noise from hi-fi are parts of daily living for many building occupants and so they suggest should be included within a future standard. This report author agrees with this statement but only when it is clearly practical and does not reduce or weaken other important sound insulation frequencies.

8.7 In countries with mandatory sound insulation testing and specific design target statements the greatest risk is to introduce a new regulatory criteria approach, which is open to larger standard deviations, less accuracy, higher reproducibility, higher repeatability and could potentially lead to delays, court action and the government facing "case law" for the testing approach to be withdrawn.

8.8 The current proposal of having two options within a future ISO standard for minimum 50 Hz and minimum 100 Hz, may allow some countries to stay with 100 Hz for a longer period while they investigate the implications on real buildings, constructions, room sizes, on-site testing conditions and most importantly the legality or robustness of a new standard criteria approach.

8.9 It may be that if a more appropriate solution or methodology for including down to 50 Hz is found then some countries may opt to utilise 50Hz minimum airborne sound insulation for room sizes of minimum ‘X’ m^3 and remain at 100 Hz for all smaller rooms.

8.10 Alternatively, if all EU countries, based on the initial outputs and partnership of COST Action TU0901, utilised a Horizon 2020 research and development approach, with regulators and industry, the full in-depth research to identify a practical and useful solution could be found for the future. This would then facilitate a future Acoustics Performance Directive (APD) but at least all countries, companies and governments could be involved from its inception. Whilst there is an Environmental Noise Directive (END) there is currently no such directive for internal noise between attached dwellings. Given that Europe can construct over 1.5 million new homes per year, will build 75 million new homes over the next 50 years and housing density is increasing and room sizes are decreasing perhaps an APD is now required.

8.11 There is no doubt that the current negativity and concerns expressed in some of the papers reviewed towards the previous proposed criteria [3] may take a longer transition period for some countries than others. Even if the proposed criteria descriptor R_{living} is abandoned and current ISO terminology is used extension to lower frequencies for airborne sound insulation is not a high priority on building standards and regulators “to do” list.

8.12 All countries considering changing the criteria should fully investigate the influence of such changes and the consequential regulatory impact assessment (RIA). If future changes to standards detrimentally reduced privacy or quality of life for occupants then a “new criteria” would not be incorporated.

9.0 Conclusions

9.1 A summary of the main papers reviewed are listed in Annex A. This is not an exhaustive list and many other letters, comment articles and papers were reviewed. However, this report has focused mainly on ‘evidence based’ materials. There is also ongoing work being undertaken by researchers in the field of addressing low frequency airborne sound insulation.

9.2 At present there is not sufficient weight of evidence, research, analysis or complaints compiled which can immediately convince some regulatory bodies and governments to alter their airborne sound insulation criteria to include low frequencies. That is not to say that complaints do not occur but such evidence is required before national standards criteria can be altered and new criteria absorbed into standards.

9.3 Of particular concern is the potential reduction in privacy or quality of life by the negative effect on mid and high frequencies if a criteria is utilised which places too much emphasis on low frequencies.

9.4 Further research is required in this area to establish an appropriate approach, methodology and criteria which can adequately reflect the occupant and ‘un-wanting’ listener’s exposure to current living noises. This cannot be done alone by using existing criteria and utilising only one existing descriptor.

9.5 Ultimately all acoustic professionals, designers, product manufacturers and governments have a role to play to ensure the optimum airborne sound insulation criteria and descriptor for our current and future generations.

	ANNEX A and REFERENCES Referenced documents	Document Type	Relates to ISO 717	Simplification	Low Frequency data sets (Lab Tests)	Low Frequency data sets (Field Tests)	Low Frequency Construction Comparisons Influence	Uncertainty / Reproducibility	Room Issues Sizes Modal Restrictions	Impact Noise	Low frequency extension YES	Low frequency extension Concerns weightings
1	ISO 717 Part 1	*ISO Standard*	X									
2	ISO 140 series	*ISO Standard*	X									
3	Scholl W., Lang J. and Wittstock V. Rating of sound insulation at Present and in Future. The Revision of ISO 717. Acta Actustica united with Acustica. Vol.97 (2011)	*Journal paper*	X	X	X		X	X			X	
4	Rasmussen B. and Rindel J.H. Sound insulation between dwellings. Descriptors applied in building regulations in Europe. Applied Acoustics. Vol 71 (2010)	*Journal paper*	X	X								
5	Rasmussen et al. Towards a common framework in building acoustics throughout Europe. COST Action TU0901. COST Office, Brussels, EU. (2013)	*Book / Report*	X	X	X			X			X	X
6	Scholl W. Revision of ISO 717: Future single number quantities for sound insulation in buildings. Euronoise. Prague. (2012)	*Conference paper*	X	X								
7	Mortensen F. Subjective evaluation of noise from neighbours - with focus on low frequencies. Publication No.53, Technal University of Denmark. (1999)	*Report*	X		X		X			X	X	
8	Park H. and Bradley J. Evaluating signal to noise ratios, loudness and related measures as indicators of airborne sound insulation. Journal of the Acoustical Society of America. Vol 126. (2009)	*Journal paper*	X	X	X							
9	Smith R.S., Macdonald R., Lurcock D, and Mackenzie R.K. Sensitivity analysis of ISO 717-1. Institute of Acoustics, Conference proceedings, Cambridge, UK.(2007).	*Conference paper*	X	X		X	X	X	X			
10	Lang J. and Muellner H. The importnace of music as sound source in residential buildings. Internoise, Innsbruck, Austria. (2013)	*Conference paper*	X			X					X	
11	Adnadevic A. et al. Noise in dwellings generated in normal home activities - general approach. Proceedings forum acusticum, Aalborg, Denmark. (2011)	*Conference paper*	X			X						
12	Masovic D. et al. Noise in dwellings generated in normal home activities - spectral approach. Proceedings forum acusticum, Aalborg, Denmark. (2011)	*Conference paper*	X			X						
13	Smith, S. et al. Part E Consultation. (2001)	*Government Consultation*										
14	Rindel J.H. On the influence of low frequencies on the annoyance of noise from neighbours. Proceedings inter-noise, Seogwipo, Korea. (2003)	*Conference paper*	X		X		X				X	
15	Living-Noise Spectrum Evaluation. Federal Institute of Technology, TGM, Vienna, Austria.	*Technical report*	X			X				X		
16	Ryu, J.K. and Jeon, J.Y. Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Applied Acoustics, Volume 72, Issue 6, Pages 336-340 (2011)	*Journal paper*			X	X				X		
17	Mahn, J. and Pearce, J. The uncertainty of proposed single number ratings for airborne sound insulation. Building Acoustics, Vol. 19(3) (2012)	*Journal paper*	X	X	X		X	X				X
18	Hongisto, V, Keranen, J., Kylliainen, M. and Mhan, J. Reproducibility of the present and the proposed single number quantities of airborne sound insulation. Acta Acustica United with Acustica, Vol. 98. (2012)	*Journal paper*	X	X	X		X	X	X			X
19	Monteiro et al. Contribution to uncertainty of in-situ airborne sound insulation measurements. Internoise 2013, Innsbruck, Austria. (2013)	*Conference paper*	X	X		X	X	X	X			X
20	Rychtarikova et al. Does the living noise spectrum adaptation of sound insulation match the subjective perception? Euronoise 2012, Prague, Czeck Republic. (2012)	*Conference paper*	X	X	X		X					X
21	Masovic, D., Pavlovic, D. and Mijic, M. On the suitability of ISO 16717-1 reference spectra for rating airborne sound insulation. Journal of the Acoustical Society of America, Vol 134 (5). (2013)	*Journal paper*	X	X		X						X
22	Hongisto et al. Disturbance caused by airborne living sounds heard through walls - preliminary results of a laboratory experiment. Euronoise 2013, Innsbruck, Austria. (2013)	*Conference paper*	X	X	X		X					X

	ANNEX A (continued) Referenced documents	Document Type	Relates to ISO 717	Simplification	Low Frequency data sets (Lab Tests)	Low Frequency data sets (Field Tests)	Low Frequency Construction Comparisons Influence	Uncertainty / Reproducibility	Room Issues Sizes Modal Restrictions	Impact Noise	Low frequency extension YES	Low frequency extension Concerns weightings
23	Smith et al. Scottish housing asociation study. (2004)	*Report*	X			X	X		X	X		
24	Hongisto et al. Acoustic satisfaction in multi-storey buildings built after 1950 - preliminary results of a field survey. Internoise 2013, Innsbruck, Austria. (2013)	*Conference paper*	X	X		X	X			X		X
25	Scottish Government legislation summary report. Section 5: Noise (2010)	*Report*	X			X	X					X
26	Wittstock, V. Standard deviation and undertainty presentation, Oslo, Norway. (2012)	*Technical report*										
27	Monteiro et al. Comparative analysis of sound insulation field measurements using different ISO 717-1 performance descriptors - Heavy separating walls and floors. Euronoise 2012, Prague, Czeck Republic. (2012)	*Conference paper*	X	X		X	X					X
28	Monteiro et al. Comparative analysis of sound insulation field measurements using different ISO 717-1 performance descriptors - Lightweight separating walls and floors. Euronoise 2012, Prague, Czeck Republic. (2012)	*Conference paper*	X	X		X	X					X
29	Rychtarikova et al. Does the living noise spectrum adaptation of sound insulation match the subjective perception? Presentation Conference Slides, Euronoise 2012, Prague, Czeck Republic. (2012)	*Conference presentation*	X	X	X		X					X
30	Rumler, W. and Seidel, J. Überarbeitung ISO717 – Rliving in der Praxis. DAGA proceedings, Darmstadt, Germany. (2012)	*Conference paper*	X	X	X	X	X					X
31	Smith Response to Part E 2001 consultation	*Technical report - Consultation Response*	X			X	X		X	X		X
32	Sass communication on behalf of CEN TC 33	*Communication*	X	X			X					X
33	Osipov, A. Mees, P. and Vermier G. Low frequency airborne sound transmission through single partitions in buildings. Applied Acoustics, Vol. 52 (1997).	*Journal paper*	X		X				X			X
34	Hopkins C and Turner P. Field measurement of airborne sound insulation between rooms with non-diffuse sound fields at low frequencies. Applied Acoustics, Vol 66 (2005)	*Journal paper*	X		X	X			X			
35	Osipov A, Mees P and Vermier G. Low frequency airborne sound transmission in buildings: Single plane walls. Proceedings of Inter-noise 96, Book 4. Inter-noise, Liverpool, UK. (1996)	*Conference Paper*	X		X				X			X
36	Evans, W. and Hartwich, O.M.. Unaffordable Housing: Fables and Myths. London: Policy Exchange (2005)	*Report*							X			
37	Rychtarikova, M. Acoustic surveys and listening tests - Part 2. Presentation Conference Slides, Final Conference, COST Action TU0901, Copenhagen, Denmark. (2012)	*Conference presentation*	X	X	X		X					X
38	Demanet, C. and Houvenghal, G. Airborne sound insulation at low frequency. Proceedings of Internoise 2012. New York. USA. (2012)	*Conference paper*	X	X	X		X	X	X			X