AIRBORNE SOUND INSULATION IN BUILDINGS - THE CONUNDRUM OF EXTENDING TO LOWER FREQUENCIES

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1 INTRODUCTION

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. At present across European countries there is a wide range of criteria which is utilised for describing the field airborne sound insulation. The *'descriptor criteria'* may include[1]:

- $D_{nT,w}$; $D_{nT,w}$+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. 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 sound insulation measurements and calculations. 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[2] via the proposed NP 16717 as outlined by Scholl et al[3].

This paper provides a synthesis of previous research on including lower frequencies such as 50 Hz for airborne sound insulation and the influence or factors of such a change. 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.

2 CHANGES TO COMMON FRAMEWORK STANDARDS

2.1 ISO 140 and ISO 717 approach

The purpose of the ISO 140[4] 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. 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.

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.

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2.2 Required evidence for change

Such standards 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. 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.

3 EXTENDING TO LOWER FREQUENCIES FOR AIRBORNE

Extending to lower frequencies within this report is in relation to including frequencies below 100 Hz to a minimum limit of 50 Hz. 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. Of the 35 countries participating within the COST Action TU0901[5] only one country (Sweden) specifically extended to lower frequencies for on-site airborne sound insulation within national standards. A particular statement which appears in the suggested[6] revisions to ISO 717 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 detailed 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 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". These shaped results were then utilised for the subjective tests undertaken and termed: Light; Light-med; Medium; Med-heavy; and Heavy.

In most 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' presented[7] did not reflect this type of behaviour for lower frequencies and so were not inclusive of real 'light' or 'heavy' structures performance. The study found that noise transmitted through light constructions is rated more annoying than noise transmitted through heavy constructions.

The difference related to the perceived lower frequency content in noise transmitted through 'lightweight' constructions which the listeners reported using the "flat-shaped" low frequency data. Nevertheless the applicability of stating a direct correlation for 'lightweight' constructions as being more annoying using a flattened "shaped" level cannot be directly linked to the type of construction without utilising actual frequency performance of both heavy and lightweight over the full frequency range.

If the use of actual 'real' frequency datasets for heavy and light constructions had been utilised during such tests then the listeners would have had a more direct comparison of subjective response to actual 'heavy *or* light' constructions.

A specific important finding found by Mortensen was "*experiments have shown than an increase in the level at low frequencies produces a higher level of annoyance, though not as much as an increase in the general level (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. Interestingly the report found that 80% of the subjects were annoyed for "*any type of construction*". Mortensen's study looking at such variation at low frequencies and its effect on 'subjective listening tests' is still very useful. The focused examination of low frequency variations on subjective responses of influence on 'annoyance and concentration' found that respondents were 1.2% more annoyed per dB (A) increase of low frequency sound.

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[9] by Smith *et al* 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.

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.

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. 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.

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

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

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. 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*". 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.

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 1.

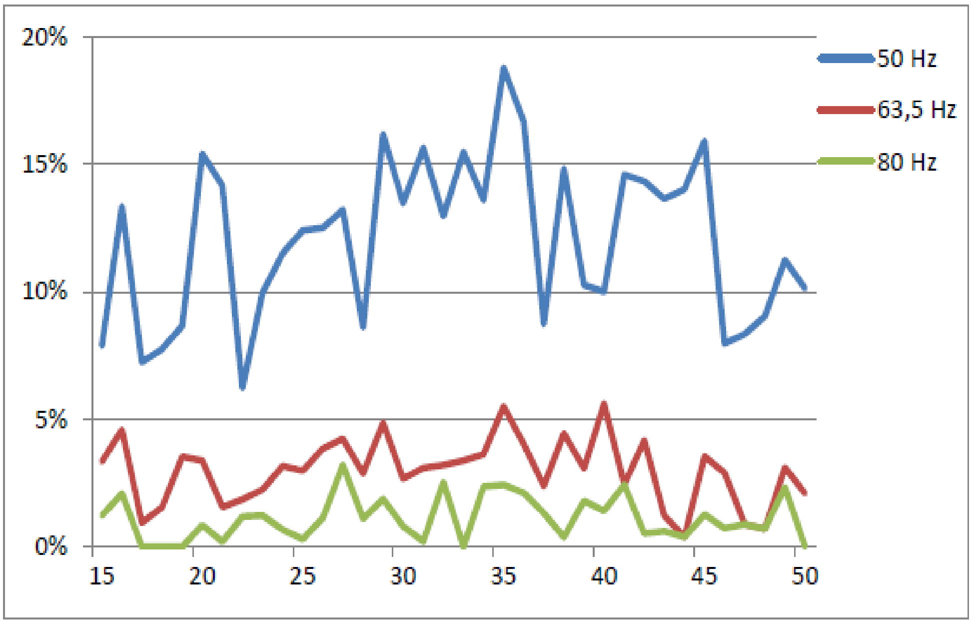

Figure 1: Percentage of lack of reverberation time measurements (non measureable) for 50 Hz, 63 Hz and 80 Hz from field tests (in-situ) [19].

5 REAL BUILDINGS, DATA AND OCCUPANTS

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).

One of the key 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. 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 paper and also highlighted by Hongisto *et al* [18], the Mortensen paper[7] did not prove that significant perception differences occur with light and heavy weight structures.

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. Both walls had the same single value rating (51 dB) when calculated for R_w+C 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. The study by Rychtarikova *et al* found that there was an overestimation of the importance of low frequencies in previous proposals to extend the airborne sound insulation requirements. 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. 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.

Hongisto *et al* [23] also 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). During 2008-09 the Scottish Building Standards Division reviewed the sound insulation performance requirements for their building code Section 5: Noise which was undertaken by Smith *et al* [24]. 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.

When extending the frequency range the reported performance of constructions can change and for some constructions, particularly lightweight, this can be quite significant. Wittstock [25] 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.

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. In 2012 Monteiro *et al* [26,27] 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.

Rumler and Seidel [28] 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. If too much emphasis is placed on low frequencies there is concern that under reporting of mid and high frequencies may occur and this may create an imbalance in the reporting on the ‘real or actual’ effective sound insulation which deals with the majority of standard living noises. 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.

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 a new criteria to sufficiently deal with low frequencies (if required) and also with mid and high frequencies. Furthermore a large majority of constructions, products and systems do not have such existing test data with extended frequency ranges, specifically field (on-site) data.

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 the guidance remained at 100 Hz for the minimum frequency the influence of the strong focus by C_{tr} on 100 Hz led to ‘more’ heavy walls being able to pass the new standards but with poor performance at mid frequencies[29]. Thus some walls would now pass that previously had failed.

As a result of these anomalies and the UK house building industry wishing to target more robust constructions and reduce the requirement for testing the development of robust details was initiated. This involved a substantial research project whereby 1,400 new homes were built with higher performing separating walls and floors to deliver a portfolio of constructions. Robust Details required a minimum 5 dB target better than building regulations and many of the construction systems designed by Napier University[30] tackled low, mid and high frequencies as a collective but still remained at a minimum 100Hz for airborne sound insulation. The outcome 10 years after the start of robust details include 750,000 new homes built with the designs, noise complaints at their lowest ever level[31] for new build properties and 99% regulatory compliance versus a 50% floors and 75% walls compliance rate before robust details started.

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. Osipov et al[32] 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.

As Scholl et al[3] indicated there are special sampling techniques as demonstrated by Hopkins and Turner[33] 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.

Osipov et al[34] 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"*. 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.

Figure 2 shows the relative 'room' square metre area (m^2) for new homes in a range of countries. The UK has some of the smallest room sizes and England has specific interest as it is the most densely populated large country in the EU.

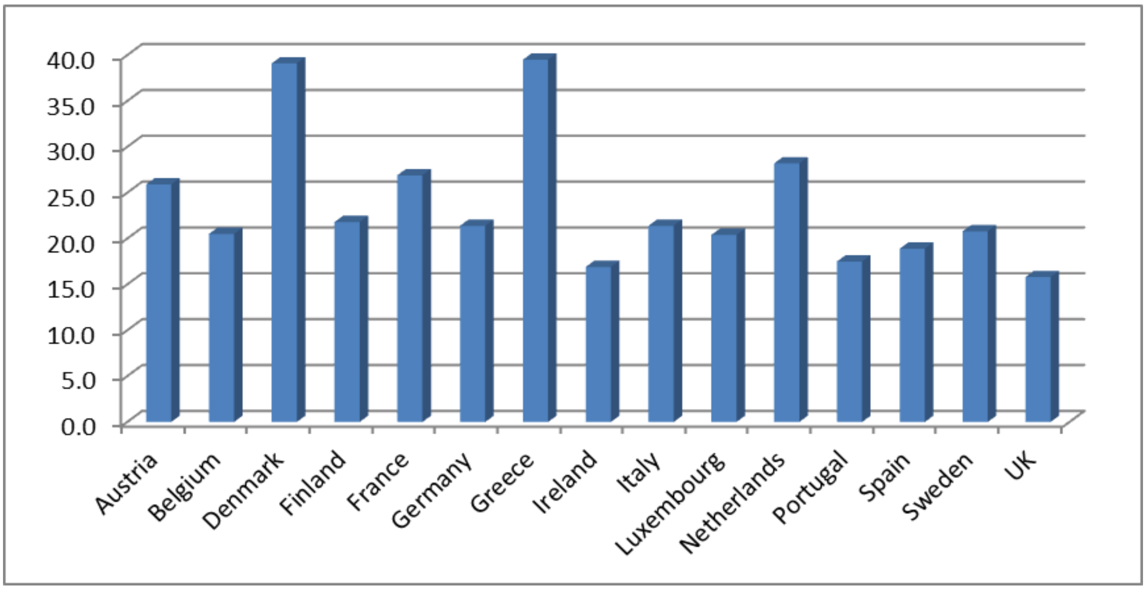

Figure 2: Average 'room' square metre area for new homes in a range of EU countries[35].

Another aspect to consider is the room height. Room heights for example in some EU new build housing are typically 2.4m to 3m 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 functionality of extending low frequencies from 100Hz to 50Hz within their building standards and regulations.

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.

6 CONCLUSIONS

Whilst theoretical and measured data show airborne mass-spring-mass resonances below 100Hz due to various constructions there is little evidence yet to suggest this correlates with complaints. There are many complexities in relation to addressing field (in-situ) low frequency measurements for airborne sound insulation. These include room sizes, modal coupling *room-plate-room,* adequately measuring reverberation times and being practical for on-site testing. The implications on building standards in each country, product manufacturers and developers by such changes must be supported by clear evidence and research before such changes are made. Emphasis on lower frequencies by current ISO weightings and spectrums too often may lead to sound transmission issues at mid and high frequencies for the 'unwanting receiver'. As such dual parameters for airborne sound insulation may be required, or remain at minimum 100Hz and raise the minimum sound insulation standard (to push up all frequencies performance) or a revised weighting curve may need to be developed to ensure any such change is robust and delivers the optimum outcomes for the building occupants across all frequencies.

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