# Sound transmission in buildings: recent developments and current challenges in measurement and prediction

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**Summary**
Research on sound transmission in buildings tends to be driven by regulations, standards, product development, and by acousticians that need measurement and prediction tools along with empirical evidence on acoustic performance that can inform design work. This paper focuses on recent developments and highlights current challenges in the measurement and prediction of sound transmission, primarily in airborne and impact sound insulation and noise form service equipment. In recent standardization work, many of the initiatives to improve the flexibility and accuracy of prediction models have required simultaneous updates to laboratory and field measurement standards. Measurement and prediction of low-frequency performance remains an important issue; however, future work on identifying appropriate parameters and limits would benefit from building consensus through simultaneous consideration of subjective evaluation alongside the practicalities and uncertainties in measuring and predicting sound insulation at low-frequencies. As prediction models for steady-state sound and structure-borne sound sources in standards reach a state of maturity there is also a need to address the prediction of parameters such as the Fast time-weighted maximum sound pressure level from transient sources such as machinery inside increasingly mechanized buildings. In general, the advances that have been made in measurement and prediction have implications relating to the skills that are required from those seeking a career in building acoustics.

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## 1. Background

Research on sound transmission in buildings is often driven by regulations, standards, product development, and by acousticians that need measurement and prediction tools along with empirical evidence on acoustic performance that can inform design work. During the 1990s there was a push to improve existing measurement and prediction standards in building acoustics. This was triggered by the EU Construction Products Directive and increasing demands for the higher acoustic performance of buildings in National regulations. The aims were to produce standards that would (a) allow a fairer comparison of the performance of individual building elements and service equipment that were tested in the laboratory, (b) introduce laboratory measurements to quantify flanking transmission between building elements and (c) allow those laboratory measurements to be used in a prediction model to estimate sound transmission in the field due to the combination of direct and flanking transmission (although this focused on heavyweight buildings). This led to a tranche of CEN and ISO standards being published between 2000 and 2010. More recently, the focus has been on updating CEN and ISO standards to (a) improve the repeatability, reproducibility and relevance of field sound insulation measurements, (b) quantify structure-borne sound power from service equipment in lightweight buildings, (c) allow laboratory measurements to quantify flanking transmission between lightweight elements and (d) extend the prediction model to estimate sound transmission in lightweight buildings.

This paper gives an overview of some of the recent developments and current challenges in the measurement and prediction of sound transmission.

## 2. Prediction

With prediction models there are competing demands from industry; these are for accurate models which are applicable to a wide range of constructions, but which are inherently simple to use. In practice, this is a difficult balancing act, and the latter requirement can only usually be met through software with GUIs that remove much of the decision making by the user.

### 2.1. EN ISO 12354 prediction model

The building acoustics frequency range (50 to 5k Hz) is sufficiently broad, and the range of constructions in modern building is sufficiently varied, that to predict the combination of direct and flanking sound transmission almost always requires some component of measured data to be included in the prediction model. For example, this could be the sound reduction index of a complex partition, a parameter that describes vibration transmission across a complex junction of walls and floors, or the radiation damping of a concrete ground floor on the underlying earth. Hence, the logic behind the prediction model that was embedded in EN ISO 12354 for airborne and impact sound insulation was to incorporate laboratory measurements as proposed by Gerretsen [1,2]. This made a direct link to laboratory airborne and impact sound insulation measurements described in the EN ISO 10140 series and laboratory flanking transmission measurements from the EN ISO 10848 series. The EN ISO 12354 model can be directly related to first-order path analysis with Statistical Energy Analysis (SEA) where the flanking transmission paths between adjacent source and receiving rooms involve no more than one junction.

The first edition of EN ISO 12354 successfully formalized the terminology needed to discuss flanking transmission (i.e. by referring to flanking paths such as Fd or Df) which, up until this point, had not entered common parlance in acoustical engineering design. It also stimulated the building acoustics community into a period of measurement activity in both the laboratory and the field to investigate if/how certain constructions that were specific to various European countries could be included in the prediction model. In addition, it highlighted the existence of building elements that did not simply fit into the framework of EN ISO 12354 (such as walls formed from perforated clay bricks where the sound reduction index in the mid- and high-frequency range was often determined by dilatational resonances rather than bending modes) and where the total loss factor was unaffected by structural connections [3].

To accommodate a wide variety of different building elements in the 2017 revisions of EN ISO 12354 and EN ISO 10848 it was found that descriptions such as ‘heavyweight’ and ‘lightweight’ were no longer helpful. This was partly because of ‘heavy’ timber elements such as CLT and the use of (heavyweight) concrete screeds on (lightweight) timber floors. For this reason, definitions of Type A and Type B elements were introduced in 2017 that were more closely aligned with the physics of the appropriate prediction model rather than whether an element was ‘light’ or ‘heavy’. With these definitions the aims were to facilitate the prediction of direct and flanking transmission and to define the appropriate laboratory measurement of flanking transmission. Type A elements are those with a structural reverberation time that is primarily determined by the connected elements (up to at least the 1k Hz one-third-octave band), and a decrease in vibration level of less than 6 dB across the element in the direction perpendicular to the junction line (up to at least the 1k Hz one third-octave band). Type B elements could then be simply defined as any element that were not Type A! Examples of Type A elements are cast in situ concrete or other solid homogeneous materials used to form walls or floors. Type B elements are typically plasterboard walls and floors. Note that an element may be defined as Type A or B over part, or parts of the frequency range. Over the building acoustics frequency range, there are some elements, such as masonry walls, that are Type A elements in the low- and mid-frequency ranges but Type B elements in the high-frequency range where there can be a significant decrease in vibration level across the element [4]. Future work will need to assess how well this approach works with elements that are defined as Type A and B over different parts of the building acoustics frequency range.

#### 2.1.1. Heavyweight buildings

For combinations of heavyweight (i.e. masonry or concrete) walls or floors, the first edition of EN ISO 12354 contained empirical relationships between the ratio of mass per unit areas for the walls and floors that form the junction, and the vibration reduction index, $K_{ij}$. These were derived from a mixture of field measurements for coupled junctions and wave theory for isolated junctions. The field measurements contained unwanted flanking transmission from high-order flanking paths, whereas EN ISO 12354 only considers first-order flanking paths. This conflicted with the approach in EN ISO 10848 to measure $K_{ij}$ from isolated junctions in the laboratory (i.e. without high-order flanking paths). To try and improve the estimate of $K_{ij}$ for junctions of heavyweight walls and floors, numerical experiments with Finite Element Methods (FEM), Spectral FEM and wave theory have been used to develop new regression curves [5] and these have been implemented in the 2017 edition of EN ISO 12354-1. There are two main changes in the approach. The first relates to the fact that in comparison to the ratio of mass per unit areas and $K_{ij}$, there is a stronger relationship between the ratio of characteristic moment impedances and the transmission loss from which $K_{ij}$ can subsequently be calculated [6]. The second relates to the assumption of frequency-independent vibration reduction indices which has been shown to be incorrect due to in-plane wave generation at the junction which becomes important in the mid- and high-frequency ranges. For this reason, regression curves were developed for the low-frequency (50 to 200 Hz), mid-frequency (250 to 1k Hz) and high-frequency (1.25k to 5k Hz) ranges [7]. The intention in future revisions is to use numerical simulations to provide $K_{ij}$ for more complex types of junctions (e.g. see [8,9]). In practice it is not feasible for EN ISO 12354 to be continuously updated with vibration transmission information on every new type of junction, whether determined from numerical simulations or laboratory measurements. Due to the complexity of many modern building elements (particularly lightweight walls and floors) and their connectivity, in the future it would be beneficial to develop an online resource where users could share information on vibration transmission for specific junctions, and document evidence of comparisons between field measurements and predictions.

In the future there is the potential to quantify the errors for heavyweight buildings which are inherent in EN ISO 12354 due to consideration of only first-order flanking paths between adjacent rooms. With demands for increasing levels of sound insulation between dwellings and increased use of resilient layers at junctions, EN ISO 12354 may not be able to provide reasonable estimates with only first-order flanking paths [10,4,11]. In addition, there are some situations (such as with service equipment in buildings) where it is necessary to predict sound transmission between non-adjacent rooms. In heavyweight buildings this requires consideration of wave conversion at junctions between bending and in-plane waves; therefore, the EN ISO 12354 model needs to be extended to account for higher-order transmission paths. The problem is that the junction between adjacent rooms is currently treated as a black box for wave conversion on the basis that we only need to know the incident bending wave power and the transmitted bending wave power. However, to predict structure-borne sound transmission across multiple junctions we need to track both the bending and in-plane wave fields. With these requirements, a challenge for the future could be to try and extend EN ISO 12354 by incorporating the option to use full matrix SEA unless validated examples are available for increasing the number of flanking paths. The latter is likely to be problematic because of the effect of spatial filtering across buildings that are essentially a box-like repeating structure and whilst Advanced SEA (ASEA) is able to give better estimates than SEA [12], it is too complex for implementation in standards and is limited to wall and floor elements and junctions that can be modelled (rather than measured).

#### 2.1.2. Lightweight buildings

The main extension in the second edition of EN ISO 12354 was to include framed timber and steel buildings as proposed by Guigou-Carter and Villot from CSTB [13,14]. For these Type B elements, the structural reverberation time is not significantly affected by the connected elements; hence $K_{ij}$ (which is effectively normalized to structural reverberation times through use of the absorption length) would not have been an appropriate parameter. However, Guigou-Carter *et al* [13] introduced an approach which fitted neatly alongside the existing model in EN ISO 12354. This requires a normalized direction-average vibration level difference, $\overline{D_{v,ij,\mathrm{n}}}$, and two radiation efficiencies, one with airborne excitation and one with mechanical excitation. Hence a new part of EN ISO 10848 (Part 5) is currently being prepared that will specify measurement procedures to determine these radiation efficiencies.

#### 2.1.3. Low-frequency issues

EN ISO 12354 aims to predict the performance of an ensemble of similar rooms; although it is not able to replicate the modal fluctuations that occur at low-frequencies in small rooms. The need to estimate the low-frequency sound insulation at the design stage in small rooms has led to informative annex that proposes use of the Waterhouse correction. Initial assessments [15] indicate that this approach provides a slight improvement, but in general the efficacy of the correction is often difficult to assess in the presence of walls or floors with mass-spring resonances in the low frequency range.

For $K_{ij}$ that is measured or predicted in the low-frequency range, the modal fluctuations are unlikely to match those that occur in a single field situation; hence the use of arithmetic average $K_{ij}$ at low-frequencies is a pragmatic solution.

Future work needs to clearly identify what can feasibly be predicted below 100 Hz using laboratory measurements for the sound insulation of individual elements and vibration trans across junctions.

### 2.2. Simplified transmission models for service equipment based on empirical databases

For industry, the prediction of sound pressure levels due to mechanical excitation of building elements by service equipment is seen as an overly complex task, particularly in lightweight buildings where the walls or floors are highly-damped with non-diffuse vibration fields and the junction details are relatively complicated. Work by Schöpfer *et al* [16] aims to reduce this complexity through the introduction of measured transmission functions that relate the spatial-average sound pressure level in a receiving room to the structure-borne sound power that is injected into a wall or floor in the building. Current work by the Rosenheim University of Applied Sciences aims to expand the database of measured transmission functions for lightweight buildings.

An alternative approach which links to EN ISO 12354 is also possible due to the introduction of the normalized flanking equipment sound pressure level in the 2017 edition of ISO 10848-1 to predict individual transmission paths [17].

### 2.3. Transient sources and heavy impacts

Inside buildings, transient sounds are generated from sources such as footsteps, dropped objects on floors, slamming doors, plumbing systems and service equipment. Langdon *et al* [18,19] and Grimwood [20] investigated human response to noise inside dwellings and related their findings to the measured sound insulation. These studies indicated that when the airborne sound insulation and impact sound insulation (albeit measured using the ISO tapping machine) was compliant with building regulations the occupants still reported annoyance from transient sound sources.

In the past, the regulation of sound insulation in the field has tended to assume steady-state sources, although some countries set requirements in their building regulations for noise levels from service equipment using Slow or Fast time-weighted maximum sound pressure levels. One of the reasons for this was the lack of validated prediction models to determine Fast (or Slow) time-weighted maximum sound pressure levels, and, more recently, questions over the measurement accuracy of $L_{p,Fmax}$ in one-third octave or octave bands.

#### 2.3.1. Prediction of Fast time-weighted maximum sound pressure levels

Due to the general acceptance of SEA and SEA-based models in building acoustics, Transient SEA (TSEA) has been investigated to predict $L_{p,Fmax}$ in rooms due to transient mechanical excitation of walls or floors [21]. The main application that has been pursued relates to heavy impacts (such as the ISO rubber ball or footsteps in bare feet) on heavyweight floors which is particularly relevant to National regulations on impact sound insulation in Korea and Japan [22]. A force plate was used to measure the blocked force from these sources in order to calculate a hybrid transient power for input into the TSEA model. TSEA predictions were validated against measurements in a heavyweight building where each of the sources in turn were used to excite a 140 mm concrete floor. Close agreement was observed between measurements and TSEA predictions of maximum Fast time-weighted velocity levels on the concrete floor and a connected masonry flanking wall, as well as the maximum Fast time-weighted sound pressure level in the room below the floor. This confirmed the implementation of transient power from the measured force time-history in the TSEA model, as well as modelling structure-borne sound transmission between the concrete floor and the masonry wall. This confirms that the TSEA model has the potential to include flanking transmission and radiation coupling between the concrete floor and the room. The example in Figure 1 shows comparisons of TSEA with measurements for the ISO rubber ball and human footsteps (barefoot, with hard-soled and soft-soled shoes). For a complex source such as footsteps it is typically necessary to consider the power injected from the entire footstep although with footsteps in socks (or bare feet) it is possible to only consider the initial heel-strike with negligible error.

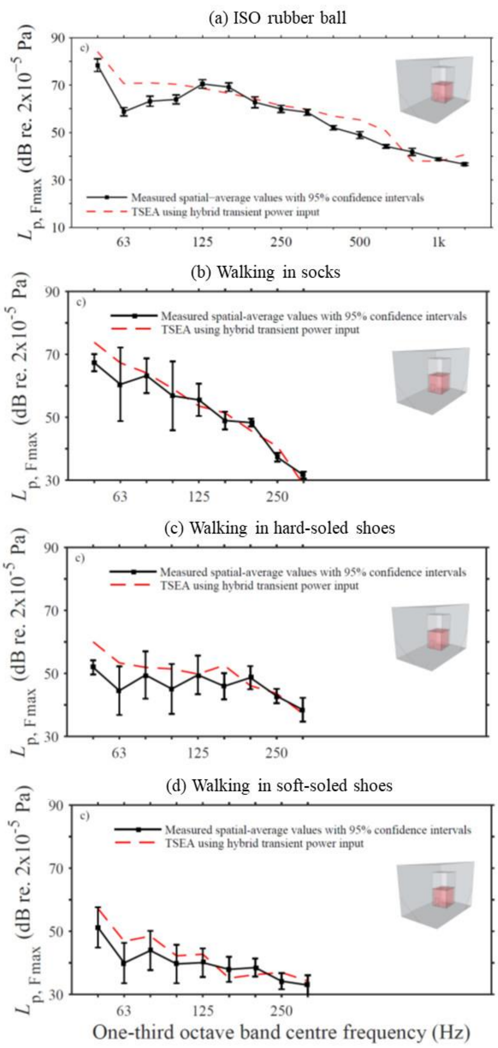


Figure 1. Comparison between TSEA and measurements in the vertical transmission suite with excitation of the concrete floor by (a) the ISO rubber ball and (b,c,d) different footsteps in terms of the maximum Fast time-weighted sound pressure level in the receiving room.

Recent work has extended the applicability of TSEA to heavyweight buildings by incorporating laboratory measurements on the impact sound insulation improvement provided by floating floors to heavy impact sources such as the rubber ball or bang machine [23]. An inverse form of TSEA (ITSEA) is used to determine the transient structure-borne sound power input from heavy impact sources into a heavyweight base floor with a floating floor. The difference in the power input with and without a floating floor gives a correction factor that can be used to modify the power input into the base floor. This allows the effect of the floating floor to be incorporated in a TSEA model of a heavyweight building.

As TSEA is not well-suited to implementation in standards, an alternative, simpler approach to the prediction of Fast time-weighted maximum sound pressure levels from service equipment is currently being sought that would fit into the framework of EN 12354. The aim is to see whether the reception plate approach could be used to quantify the structure-borne sound power from machinery using short $L_{eq}$ values, that could then employ an empirical correction to calculate $L_{p,\mathrm{Fmax}}$ [24].

## 3. Measurement

### 3.1. Low-frequency airborne and impact sound insulation

A common issue that occurs in both measurement and prediction is the low-frequency performance in the field.

#### 3.1.1. Laboratory measurement of airborne sound insulation using sound intensity

EN ISO 15186-3 which uses sound intensity tends to provide a better estimate of the sound reduction index below 100 Hz than EN ISO 10140 [25]. However, there continues to be relatively low interest from industry and therefore relatively few test laboratories offer the measurement. This is partly due to the additional time (and therefore cost) required to carry out the sound intensity scanning, but also a reluctance from industry to pay more money for a lower (but more accurate) sound reduction index. This means that the majority of low-frequency measurements quoted by manufacturers provide a weak basis for product comparison. To try and move towards more accurate low-frequency estimates it could be worth instigating a Round Robin involving a systematic comparison of airborne and impact sound insulation using EN ISO 10140 and 15186-3 to allow guidance to be developed on which laboratories could quote reasonable estimates below 100 Hz using EN ISO 10140. For example, only if ISO 10140 and ISO 15186-3 results were within *X*dB for the 50, 63 and 80 Hz bands and a certain type of element, then either method could be quoted by that particular laboratory.

Whilst ISO 15186-3 allows a fairer comparison of the low-frequency performance of wall/floor products, there is no evidence available to show that it would significantly improve the accuracy of predicted sound insulation in the field for room volumes <50m$^3$ when incorporated into models such as EN ISO 12354. Available evidence from numerical modelling [26] would suggest that this is unlikely due to the influence of the modal sound fields in the source and receiving rooms. For the future, users of EN ISO 12354 need more information on its efficacy to make reliable judgements on the value of predictions below 100 Hz.

### 3.1.2. Laboratory measurement of the sound reduction improvement index

Linings are commonly used on separating and flanking elements (e.g. floating floors, thermal wall linings on masonry/concrete walls, suspended ceilings). To quantify their performance the sound reduction improvement index, $\Delta R$, is measured according to EN ISO 10140 with airborne excitation. However, for many heavyweight flanking elements it is only resonant transmission via the lining, $\Delta R_{\text{Resonant}}$, that is relevant when incorporated in EN ISO 12354 models. This applies to the situation where the base wall or floor is mechanically excited. $\Delta R$ includes non-resonant (mass law) transmission below the critical frequency and if the base wall or floor is porous, non-resonant transmission through the pores. Below the critical frequency of non-porous base walls and floors, $\Delta R_{\text{Resonant}}$ will usually be lower than $\Delta R$. As linings typically introduce mass-spring or mass-spring-mass resonances which are responsible for significant sound transmission in the low-frequency range, this issue potentially needs to be addressed to improve predictions using EN ISO 12354.

The measured sound reduction improvement indices, $\Delta R$ and $\Delta R_{\text{Resonant}}$, for three different wall linings on the same masonry wall are shown in Figure 2 [4]. This indicates that mechanical excitation tends to emphasize the dip at the mass–spring–mass resonance, and it is likely that this will occur when service equipment is attached to one surface of the element. However, a rigorous set of comparisons with flanking laboratory tests according to EN ISO 10848 would be needed to show that this emphasis on the mass–spring–mass resonance occurs with flanking elements in typical airborne and impact sound insulation scenarios.

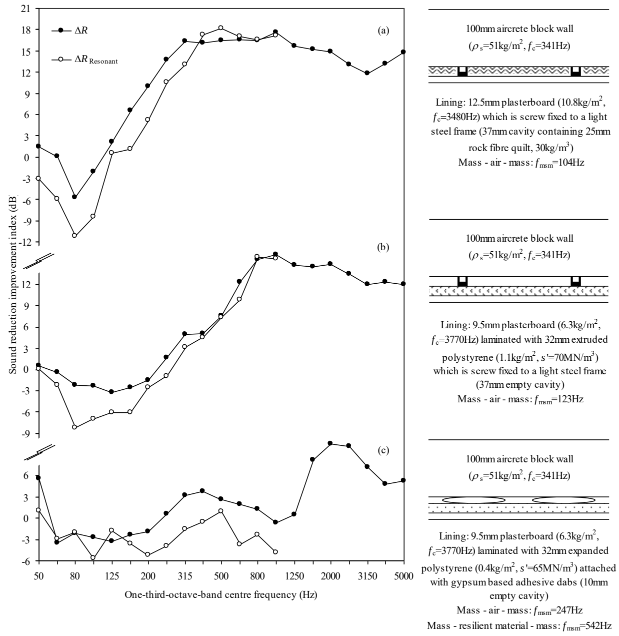


Figure 2. Measured sound reduction improvement indices, $\Delta R$ and $\Delta R_{\text{Resonant}}$, for three different wall linings on the same solid masonry wall. Note that $\Delta R_{\text{Resonant}}$ is only shown below the thin plate limit.

### 3.1.3. Laboratory measurement of radiation efficiency

As input data, EN ISO 12354 requires the resonant sound reduction index which can be calculated from knowledge of the sound reduction index and the radiation efficiencies with mechanical and acoustical excitation. Hence a new part of EN ISO 10848 (Part 5) is currently being drafted that will specify measurement procedures to determine these radiation efficiencies.

### 3.1.4. Field airborne sound insulation

In the rating of airborne and impact sound insulation, the use of low-frequency spectrum adaptation terms down to 50 Hz is still uncommon in European building regulations although it is included in some classification schemes [27]. Sweden has gone further than many countries in looking to provide low-frequency sound insulation down to 20 Hz [28]. However, the field measurement standard EN ISO 16283 still uses 50 Hz as the lower limit, and for rooms with volumes <25 $m^3$, corner measurements are used to try and improve repeatability, reproducibility and relevance of results from the 50, 63 and 80 Hz one-third octave bands [29,30,31]. Future revisions will need to consider whether 50 Hz is still a suitable lower limit.

#### 3.1.5. Field impact sound insulation

After decades of discussion about the inherent problems with the ISO tapping machine (e.g. see [32,4]), the rubber ball was introduced as an alternative source (described as a heavy impact source) in EN ISO 10140 for laboratory tests and in EN ISO 16283-2 for field tests. For regulatory purposes the rubber ball is still only used in Japan and Korea. This is partly because countries in Europe and North America have spent those same decades finding workarounds to account for the foibles of the tapping machine. However, as heavy impacts are still perceived to be a worldwide problem, particularly with lightweight buildings, the rubber ball may still be useful for classification schemes to ensure high-performing lightweight constructions.

#### 3.1.6. Field façade sound insulation

As with other field measurements there remains a focus on quantifying the uncertainty (e.g. see [33]) which could potentially feed into ISO 12999-1. In addition, practical measurement issues have been raised where it is not always possible to position a microphone at a distance of 2 m from the tested façade. To overcome this issue, an alternative approach using a microphone sweep has been proposed [34].

#### 3.1.7. Future challenges

The setting of regulatory standards for low-frequency airborne sound transmission remains an important issue, and in recent years there have been studies assessing whether it is necessary to include results below 100 Hz when determining single-number quantities (e.g. see [35,36,37,38]). Some of these studies provide conflicting evidence as to what might be essential and practical to implement in a regulatory framework, although the conclusions drawn from the evidence in some studies has also been criticized [39].

Some laboratory studies on the subjective evaluation of noise in buildings tend to assess loudness as it is more complex to realistically assess annoyance. Further insights in a laboratory setting might be gained through the measurement of physiological responses to noise inside buildings. Whilst physiological responses have been used in environmental noise, it is at an early stage in the assessment of noise inside buildings relating to low-frequency airborne or impact sounds [40,41].

Future work could seek to build consensus through simultaneous consideration of subjective and psychophysiological evaluation (in the field and the laboratory) alongside the practicalities of measuring and predicting sound insulation at low-frequencies along with the inherent uncertainty (e.g. see [42,43,44]).

### 3.2. Structure-borne sound power from service equipment

In the 2017 edition of EN 15657, the laboratory determination of the structure-borne sound power from service equipment using the reception plate approach [45,46] has been expanded from low-mobility receiver structures to any source-receiver mobility condition. Future enhancements could consider specifying low-frequency sampling strategies on the reception plate [47].

In the 2017 edition of EN ISO 10848-1, two approaches are introduced for structure-borne sound sources in buildings to estimate sound pressure levels in a receiving room due to structure-borne excitation by service equipment, a normalized flanking equipment sound pressure level and a transmission function. The former assumes that flanking transmission is limited to one junction (or no junction if the element supporting the equipment is the separating element), and the latter considers the combination of direct (if any) and all flanking transmission paths.

Figure 3 shows example transmission functions for a single type of construction [16] which indicates the potential variation that might be expected between similar dwellings.

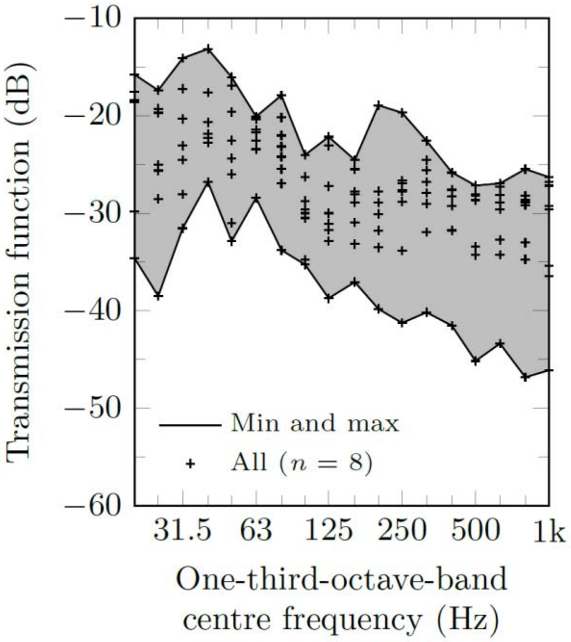


Figure 3. Field measurements of transmission functions measured with transient excitation in adjacent rooms for a timber frame single wall with plasterboard on both sides.

### 3.3. Fast time-weighted maximum sound pressure levels for impact sound insulation and service equipment

Maximum sound pressure levels in frequency bands are commonly used for environmental noise and building acoustics measurements of sound pressure levels from heavy impacts on floors and service equipment. To investigate signal processing errors due to Fast or Slow time-weighting detectors when combined with octave band filters, one-third octave band filters or an A-weighting filter, four different commercially-available sound level meters were used to quantify the variation in measured maximum levels using tone bursts, half-sine pulses, ramped noise and recorded transients [48]. Tone bursts indicated that Slow time-weighting is inappropriate for maximum level measurements due to the large bias error. The results also show that there is more variation between sound level meters when considering Fast time-weighted maximum levels in octave bands or one-third octave bands than with A-weighted levels.

Figure 4 shows a comparison of the frequency spectra of two measured transients using a software-based sound level meter along with the relative $L_{Fmax}$ from the four commercially-available sound level meters in octave bands and one-third octave bands. Transient No. 1 is a door slamming and No. 2 is a single impact on a concrete floor in the lower room of a transmission suite from the ISO rubber ball dropped from a height of 1 m. Significant differences (up to 8dB) occur between the four commercially-available sound level meters in the low-frequency range (however, in terms of A-weighted levels the variation is up to 1dB.). This suggests that more work is needed to specify the signal processing used in SLMs.

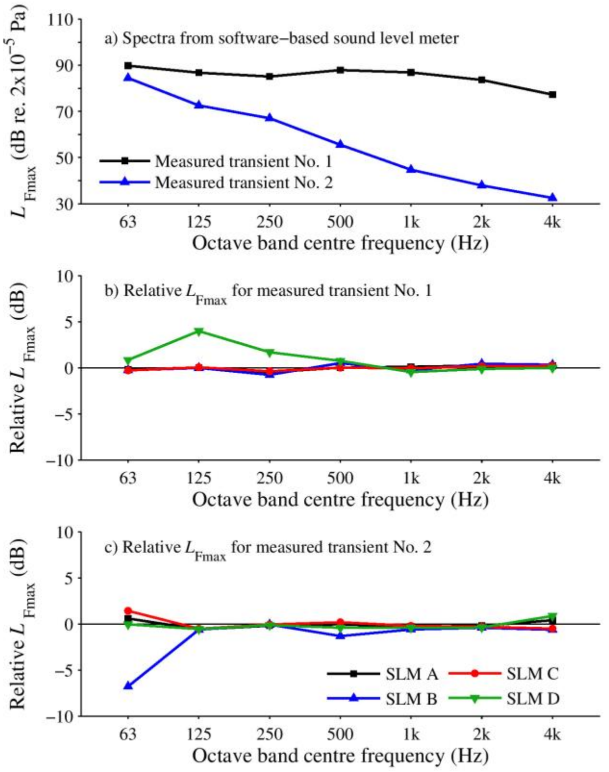


Figure 4. Comparison of measured transients for octave band filters from commercially-available sound level meters (A,B,C,D).

### 3.4. Rain noise

In the last few decades, rain noise on roof glazing and lightweight roofs has become an increasingly important issue for commercial buildings and schools. A laboratory measurement standard using artificial rain on roof glazing and roof elements was introduced in 2006. However, this relies on two idealizations of rain (defined as heavy and intense rain) which are not simply related to natural rainfall. To help understand the link between results measured using artificial rain in the laboratory and natural rain, recent work at Liverpool has used wavelet deconvolution to develop empirical models for the force applied by raindrops on dry and wet surfaces [49]. Figure 5 indicates how experimental measurements can be closely approximated with empirical models, but not with idealized drop shape models or other models from Roisman *et al* (2009) and Marengo *et al* (2011). The next step is to apply the empirical models to simulate natural rainfall.

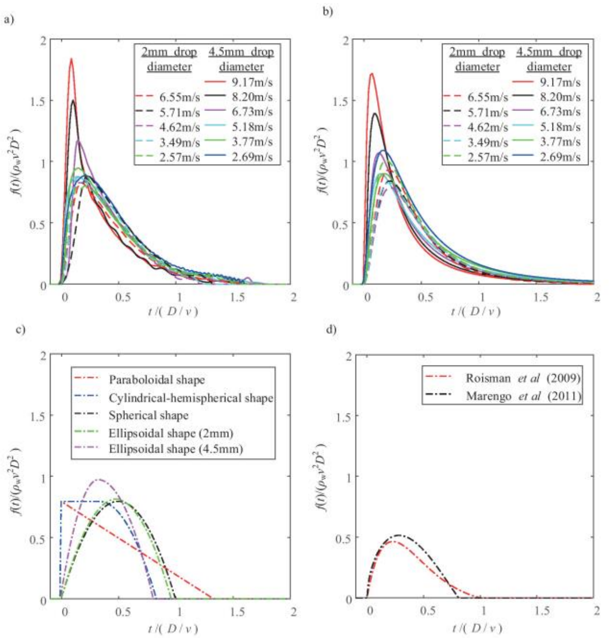


Figure 5. Comparison of dimensionless force between measurements using the wavelet approach and different models for 2 and 4.5 mm drops with different drop velocities impacting a dry glass surface (a) wavelet measurement (b) empirical formulae (c) idealized drop shape model (d) Roisman *et al* (2009) and Marengo *et al* (2011) models.

## 4. Concluding remarks

Advances in measurement and prediction have implications relating to the skills required from acousticians planning a career in building acoustics. Developments in modern construction techniques require acousticians to successfully (re)design buildings without negatively impacting people's health and well-being. However, in building acoustics, research activities have become slightly marginalized and only a few research groups are able to cover the three key aspects of measurement, prediction and subjective evaluation. As a consequence, industry is lacking practitioners with in-depth expertise in building acoustics, particularly those who also have the background to take an interdisciplinary outlook on problems. To meet future demands for such skilled practitioners, a current EU Marie Curie training network ACOUTECT (merging 'acoustics' and 'architect' to indicate the important role that acousticians have in building design) is in progress. ACOUTECT aims to establish a long-lasting European-wide training programme on building acoustics alongside an innovative research programme. With these objectives, ACOUTECT aims to equip early-stage researchers with skills to ensure acoustic quality of modern and future building concepts, and give them opportunities for a career in industry or academia within the field of building acoustics. The training and supervision to reach these objectives is offered by the ACOUTECT consortium which is composed of five universities (TU Eindhoven, Chalmers, Liverpool, Aalto, KUL) and seven non-academic participants. The project aims to promote interdisciplinary activities, innovative training and mobility of the researchers within the project. (See http://www.acoutect.eu/)

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