inter.noise
HAMBURG 2016

Satellite Symposium on
Building Acoustics

Predicting and measuring sound transmission in buildings at low frequencies

Carl Hopkins
Acoustics Research Unit
UNIVERSITY OF LIVERPOOL

Several questions…which generate more questions

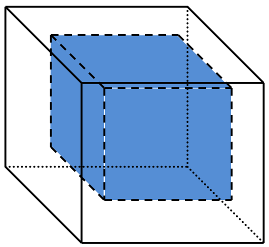
1. What aspects of the sound field do we want to measure/predict at low-frequencies?
2. As real rooms are not usually empty, box-shaped spaces, how confident can we be about predicting the sound field in source and receiving rooms at low-frequencies?
3. Does incorporating coupling parameters across junctions of finite heavyweight plates improve the prediction of low-frequency flanking transmission?
4. Can Fast time-weighted sound pressure levels be predicted for low-frequency impacts on floors such as footsteps?
5. Can transmission suites really give us low-frequency airborne sound insulation data that are useful at the design stage?
6. Moving forward, how might we more effectively bring together research on subjective evaluation, rating, measurement and prediction of low-frequency sound insulation?

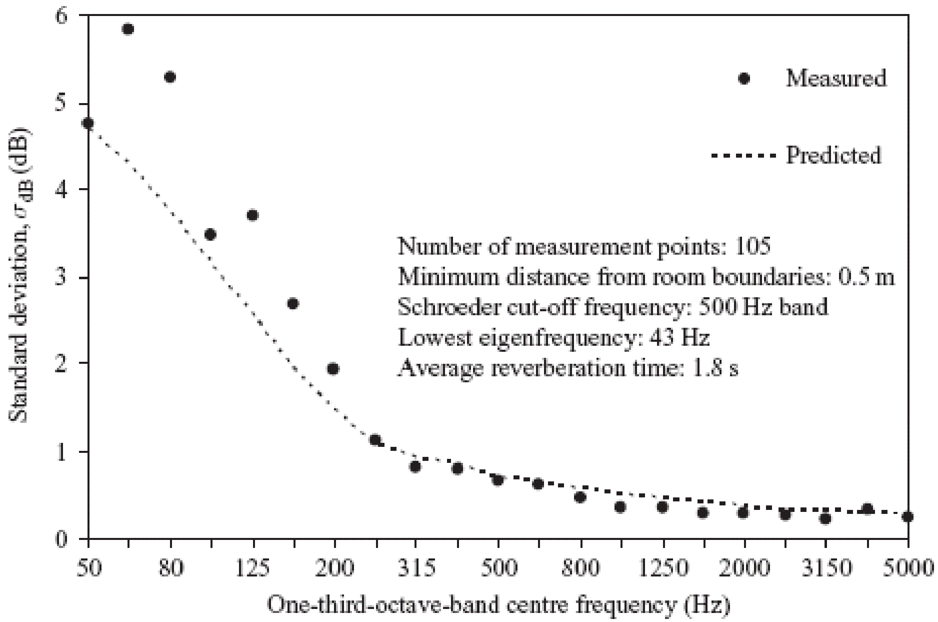
What aspects of the sound field do we want to measure/predict at low-frequencies?

Spatial variation in sound pressure level

- In typical rooms the spatial variation in the sound pressure level increases at low-frequencies which increases the uncertainty in the spatial-average sound pressure level

34m³ receiving room





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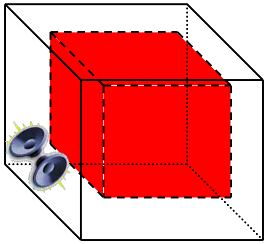
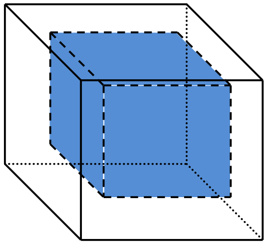
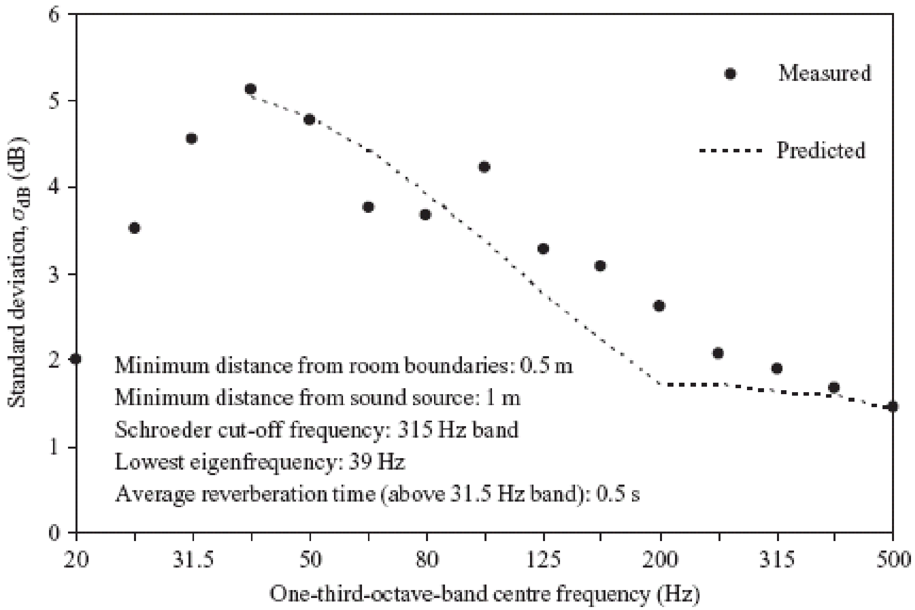
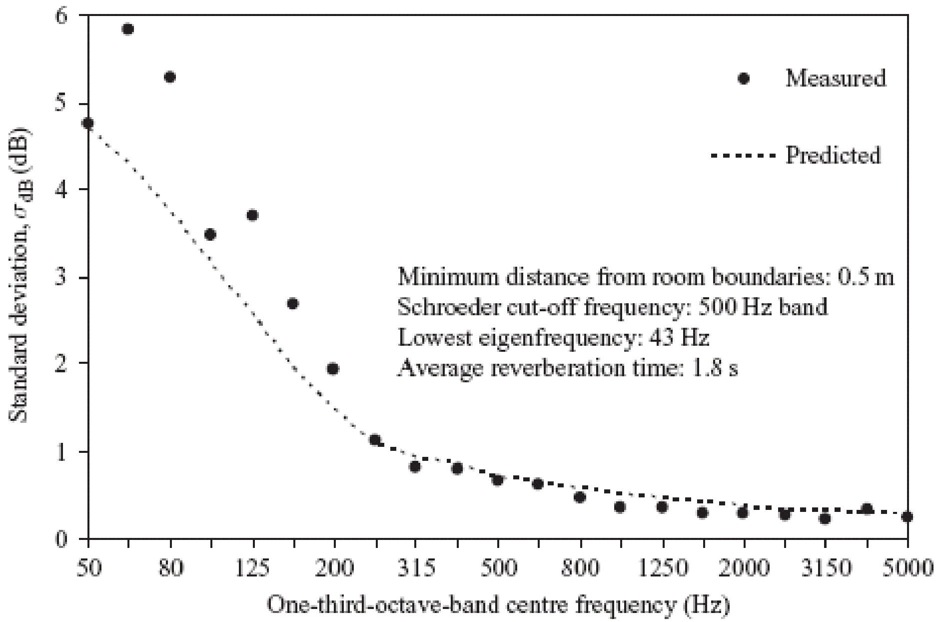
29m^3 source room



34m^3 receiving room



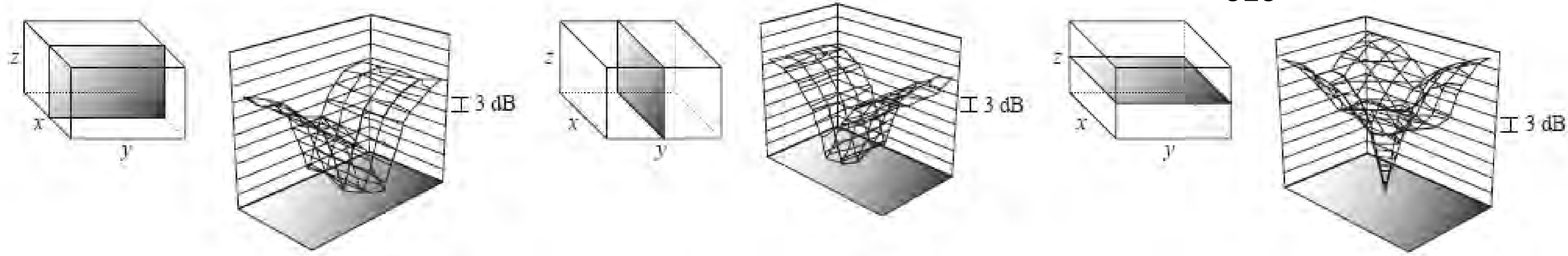




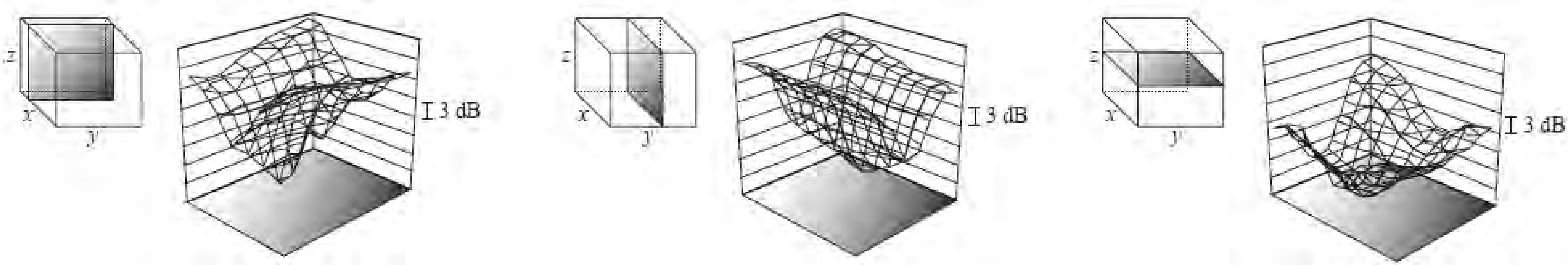
Modal response in small rooms

- Room volumes <25m^3 often have <5 room modes below 100Hz
- Maximum differences between the lowest level in the central zone of the room and the highest level that is ≈0.5m from the room boundaries can be 17 – 28 dB

34m^3 receiving room 50Hz one-third octave band (f_{010} is 47Hz)



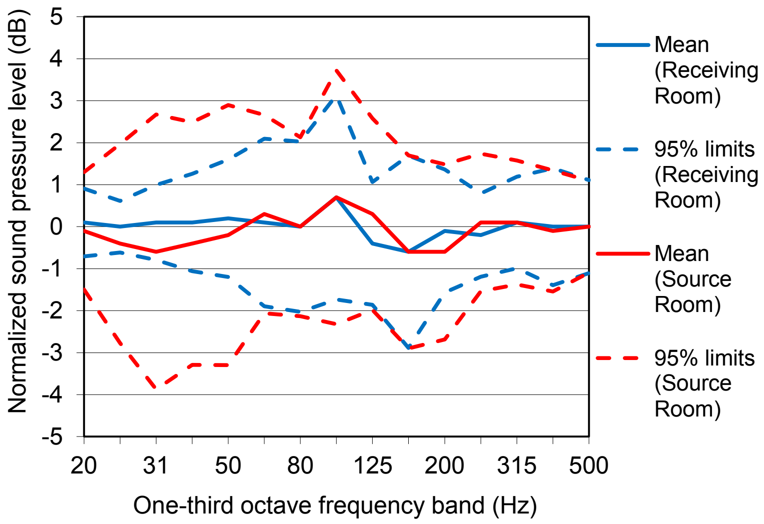
18m^3 receiving room 80Hz one-third octave band (f_{001} is 74Hz, f_{110} is 87Hz)



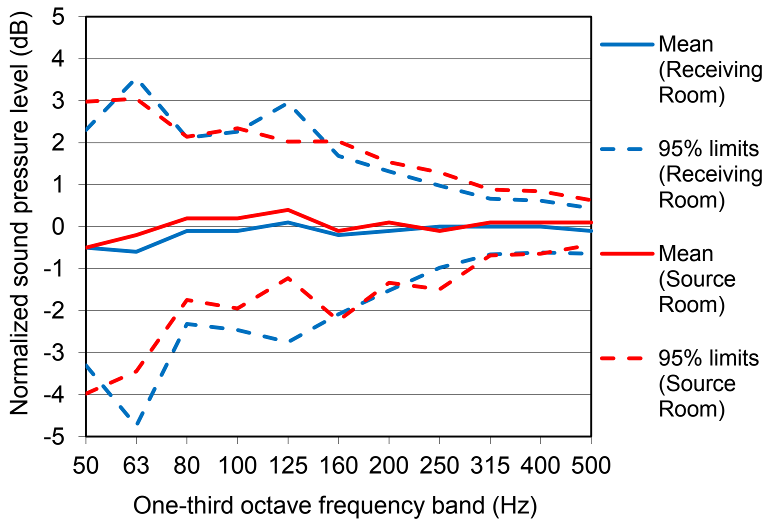
Measuring average sound pressure levels in the central zone of a room

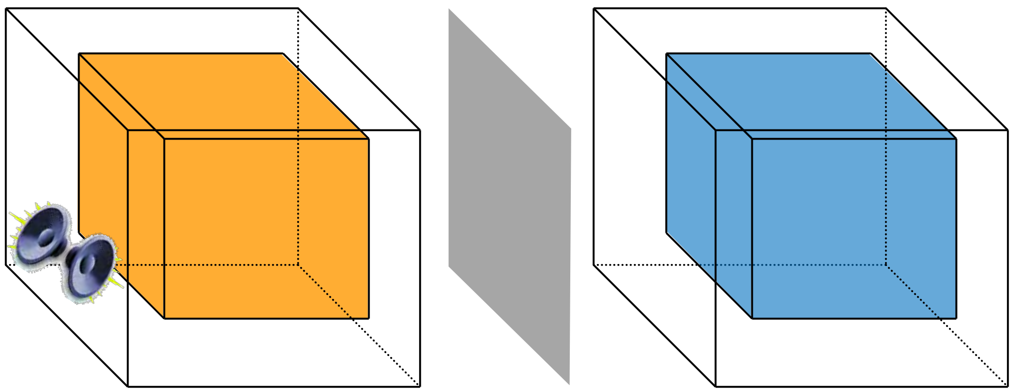
Different averages of 5 microphone positions in central zone *normalized to average of central zone*

29m³ source room and 18m³ receiving room
Timber frame



39m³ source room and 34m³ receiving room
Masonry





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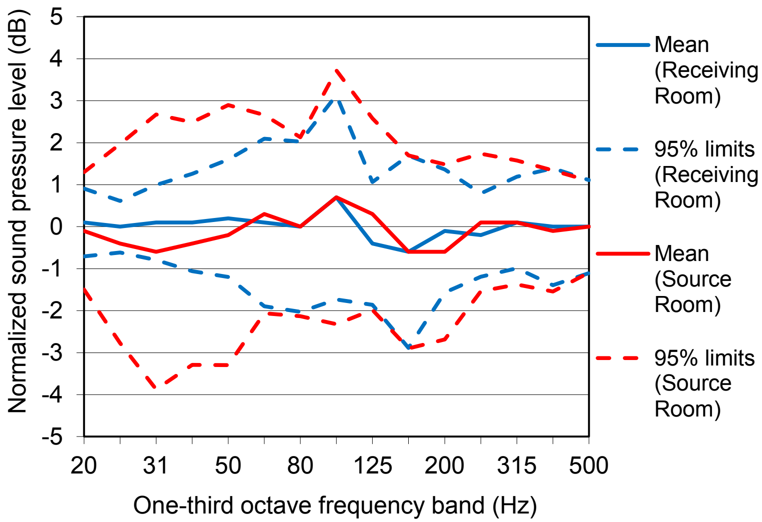
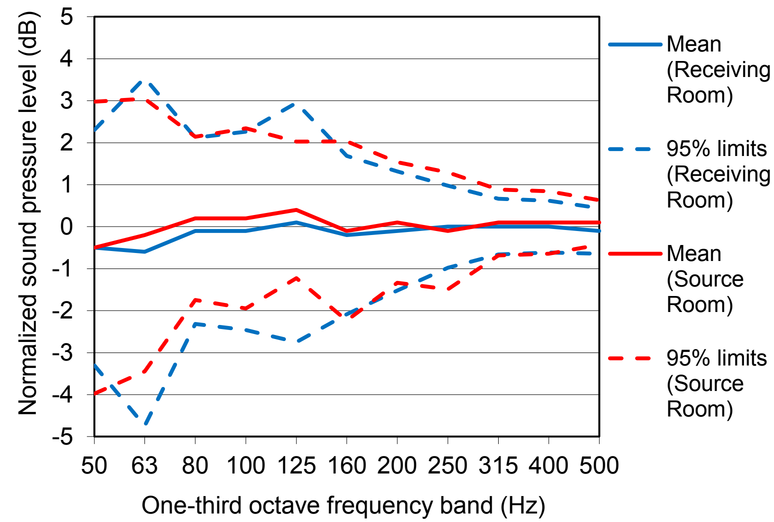
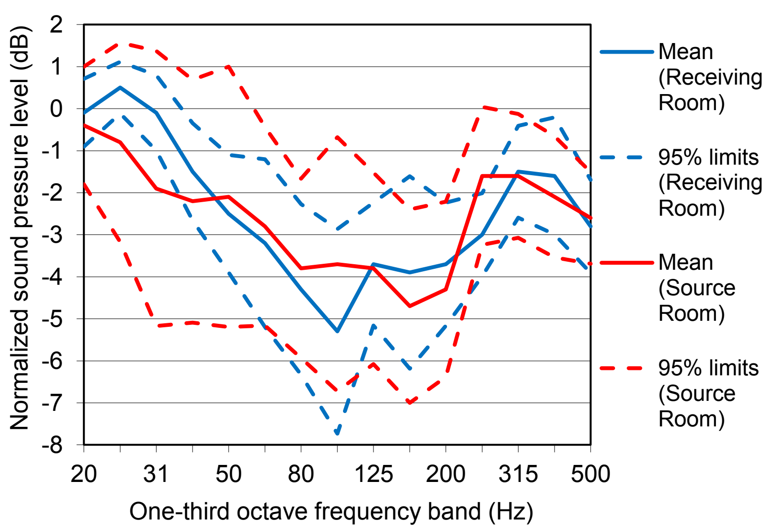
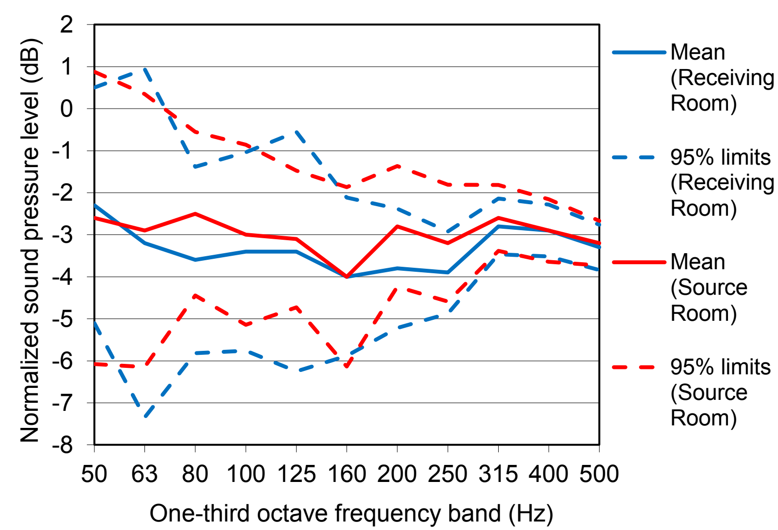




Different averages of 5 microphone positions in central zone *normalized to average of entire room*



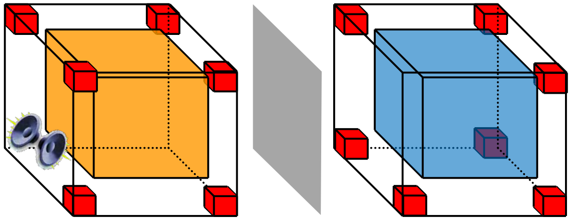


Measuring field sound insulation below 100Hz

Using the low-frequency procedure to estimate the room average SPL

- Repeatability is improved by making use of additional microphone positions to sample sound pressure in the corners of rooms below 100Hz
  - Similar approach is used in ISO 10052 for low-frequency noise measurements from service equipment in buildings
- Use the central zone SPL measurement and the corner SPL to estimate the average SPL for the entire room volume
- This can be achieved using an empirical weighting according to

$$L_{LF} = 10\lg\left[\frac{10^{0.1L_{Corner}} + (2 \cdot 10^{0.1L})}{3}\right]$$

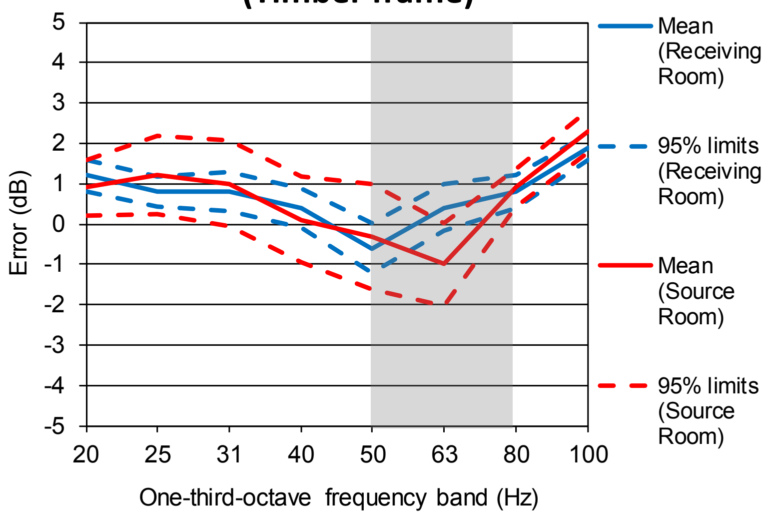


Measuring field sound insulation below 100Hz

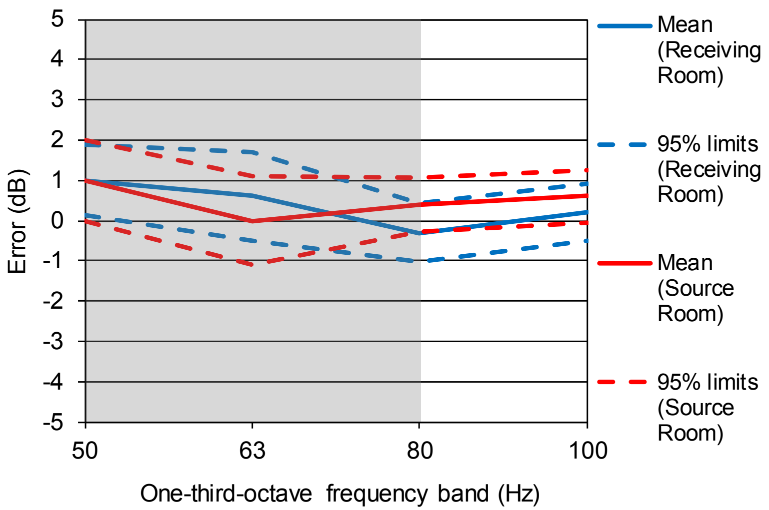
Using the low-frequency procedure to estimate the room average SPL

- For the 50, 63 and 80Hz one-third octave bands
  - mean error is approximately 0dB when using the low-frequency procedure to estimate the average SPL over the entire room volume
  - 95% confidence intervals for the low-frequency procedure are similar or smaller than those in the central zone for different sets of stationary microphone positions between 100Hz and 500Hz

29m³ source room and 18m³ receiving room (Timber frame)



39m³ source room and 34m³ receiving room (Masonry)



Measuring field sound insulation below 100Hz

Using the low-frequency procedure to estimate the reverberation times

- ≈250 individual RT measurements using forward filter analysis with interrupted noise in unfurnished timber and steel frame buildings

One-third-octave band centre frequency (Hz)	% satisfying *BT* > 8 criterion	
	Using individual decay curves	Using ensemble average decay curves
50	37 %	33 %
63	48 %	57 %
80	87 %	86 %

Octave band centre frequency (Hz)	% satisfying *BT* > 8 criterion	
	Using individual decay curves	Using ensemble average decay curves
63	98.8 %	100 %

What else do we need to know?

- Would there be any benefit in continuing to measure sound pressure levels in the 50, 63 and 80Hz one-third octave bands for diagnostic purposes but only quoting and rating with a value for the 63Hz octave band?
- In a future revision of ISO 16283 should we consider extending the approach to the 31.5Hz octave band?
  - If there were no room modes below 50Hz, standardization to reverberation time would not be appropriate
- Here we have only considered steady-state response, but impact sound insulation studies from Korea indicate that for heavy impacts there are other features such as decay rate which could be important when assessing subjective response.
  - Is it feasible to include these in regulations?
  - Can they be predicted sufficiently accurately?

As real rooms are not usually empty, box-shaped spaces, how confident can we be about predicting the sound field in source and receiving rooms at low-frequencies?

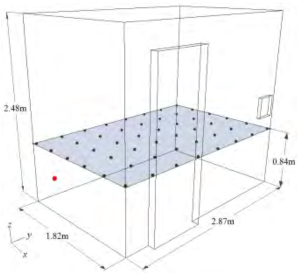
Sound field in a 13m^3 box-shaped room

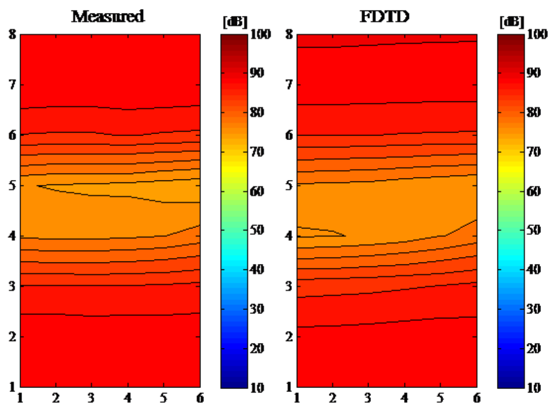
Effect of porous material near the centre of the room

Axial

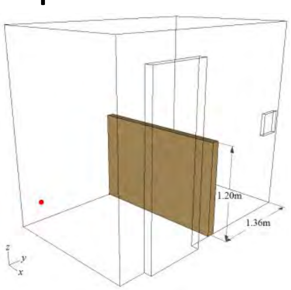
$f_{010} \approx$ 60Hz

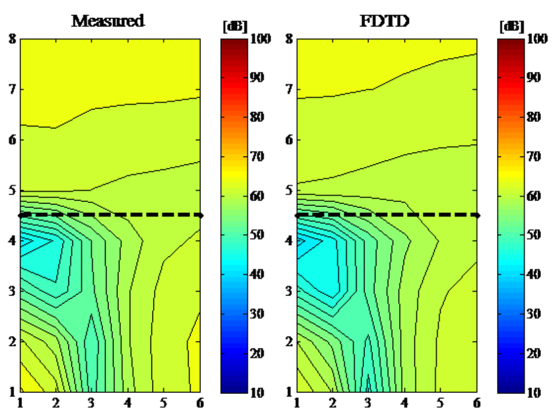
Empty room





With 100mm porous slab

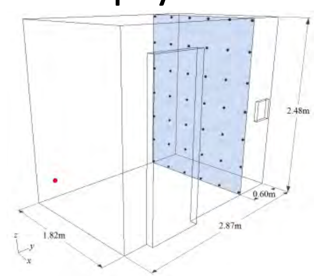


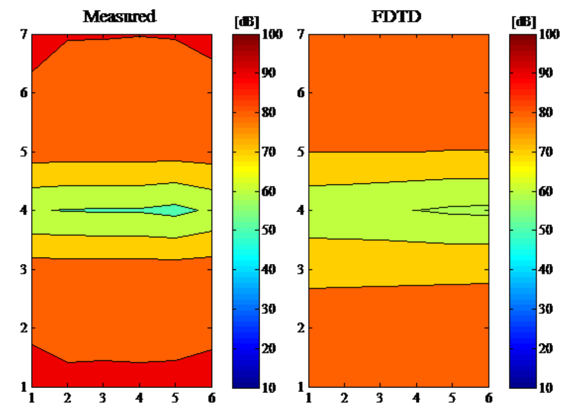


Axial

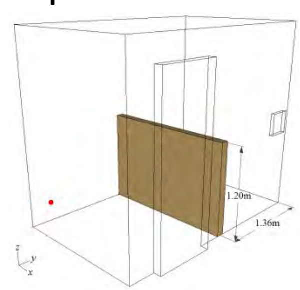
$f_{001} \approx$70Hz

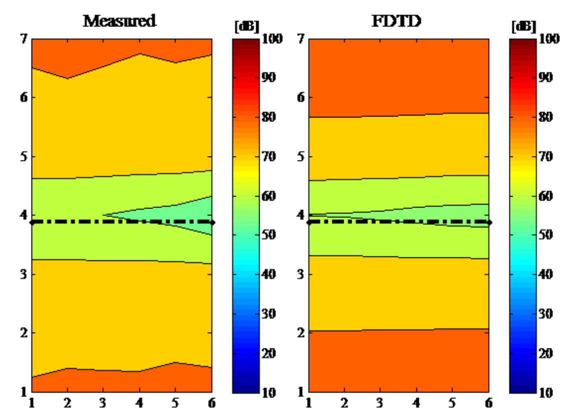
Empty room





With 100mm porous slab





● Subwoofer

Sound field in a 13m^3 box-shaped room

Effect of porous material near the centre of the room

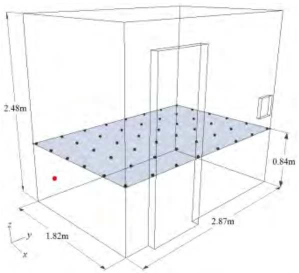
Tangential

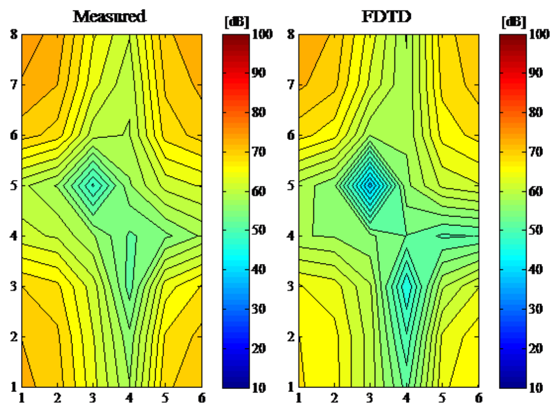
$f_{110} \approx$ **112Hz**

Oblique

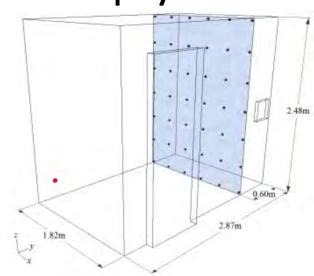
$f_{111} \approx$**131Hz**

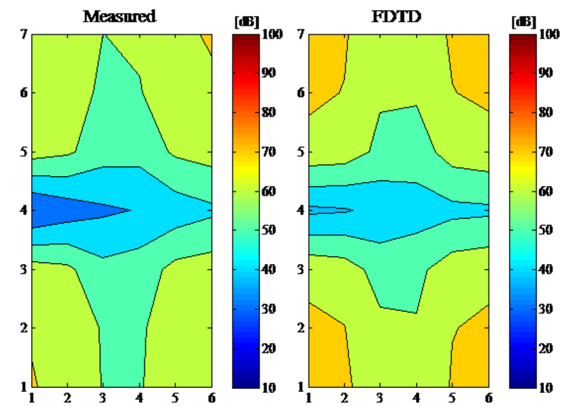
Empty room



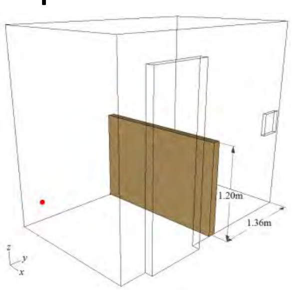


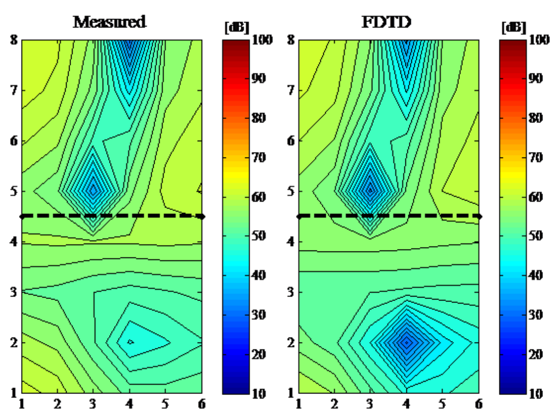
Empty room





With 100mm porous slab





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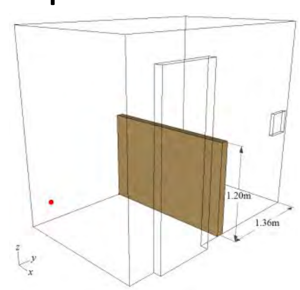
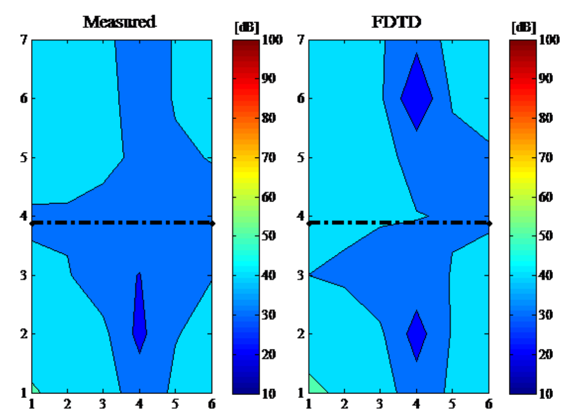




- Close agreement for axial, tangential and oblique modes suggests that sound fields in source rooms could be modelled with ‘idealised’ absorbent furniture

What else would be useful to know?

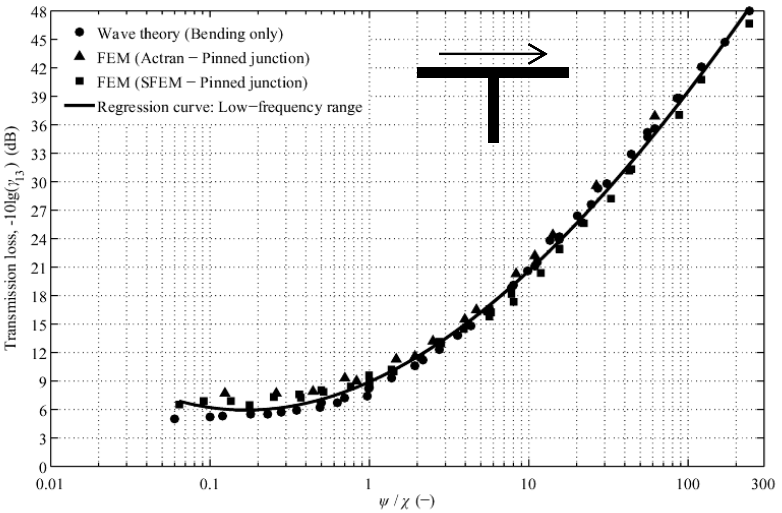
- FEM or FDTD models can predict the effect of furnishing on the sound field in source/receiving rooms at low-frequencies, but how could this be efficiently incorporated into prediction of the sound transmission between rooms?

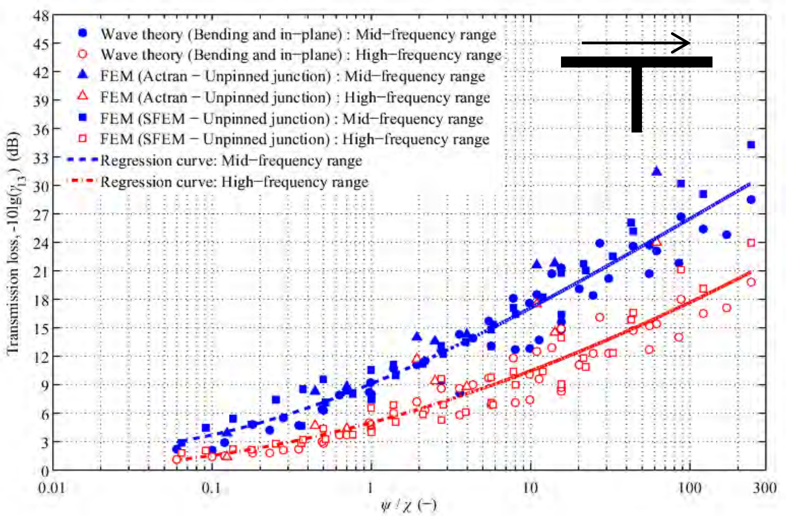
- Can we use a statistical or probabilistic approach to the modelling of deterministic sound fields?

Does incorporating coupling parameters across junctions of finite heavyweight plates improve the prediction of low-frequency flanking transmission?

Incorporating coupling parameters from junctions of finite plates inside SEA models

- Recent work has sought to improve the estimates of K_{ij} in EN12354 using FEM and wave theory to give frequency-average values
  - in the low-frequency range to try and account for the effects of low mode counts and low modal overlap
  - in the mid- and high-frequency ranges to try and account for the effect of in-plane wave generation
- However with EN12354 the overriding limitation might be the fact that it only considers flanking paths that cross one junction



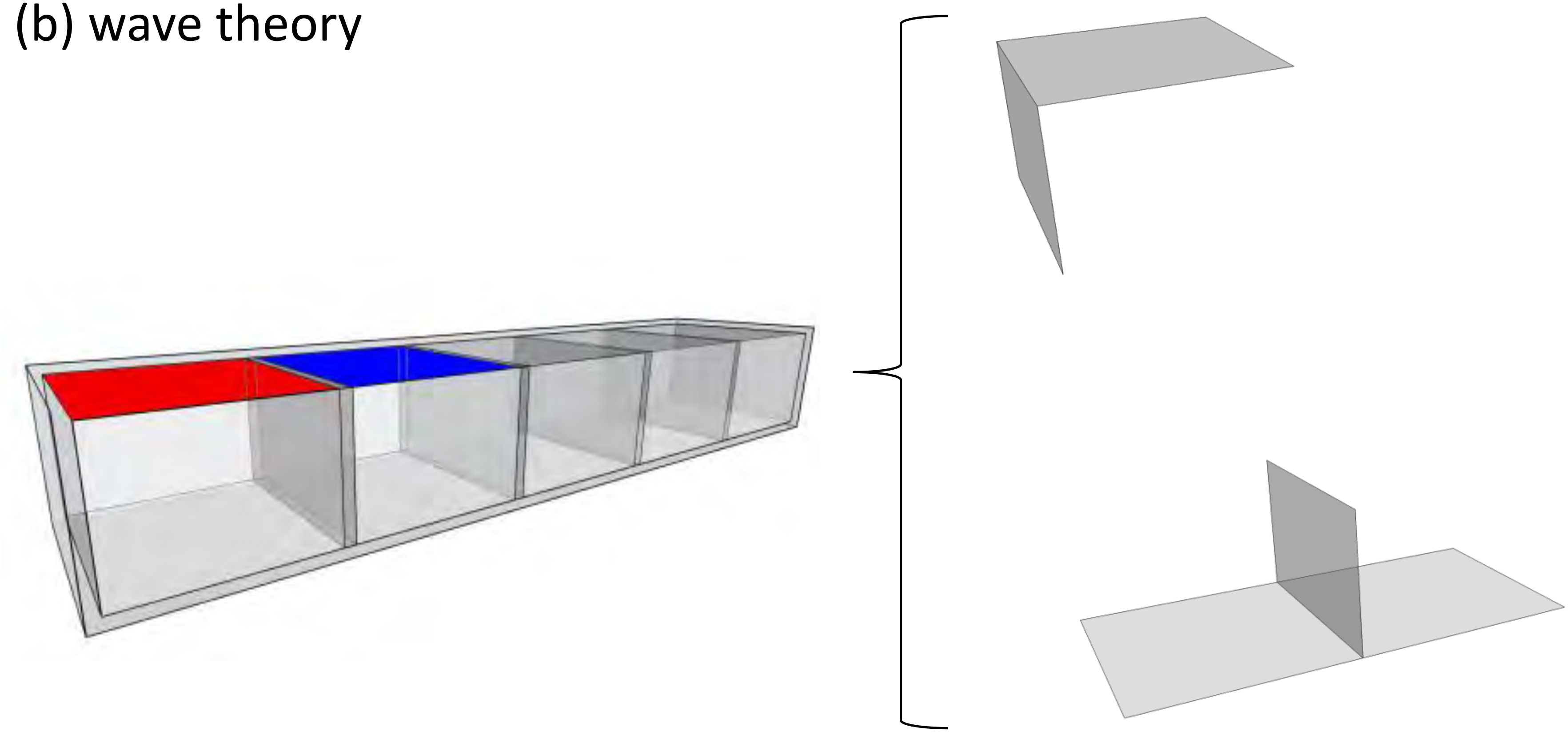


Incorporating coupling parameters from junctions of finite plates inside SEA models

- Example: Masonry/concrete building with a corridor of five rooms
- Structure is composed of L- and T-junctions for which Coupling Loss Factors (CLFs) are calculated using:

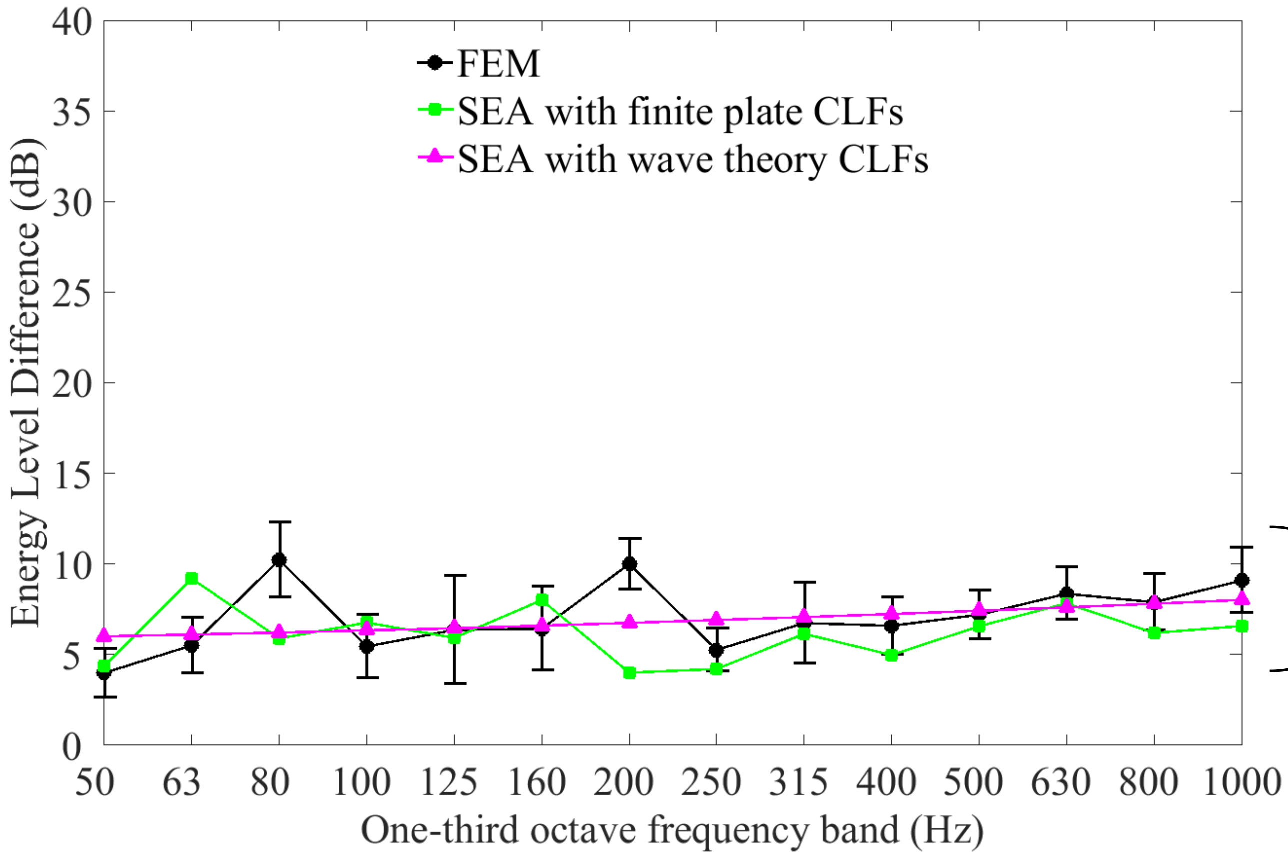
  (a) analytical models of isolated junctions formed from finite plates

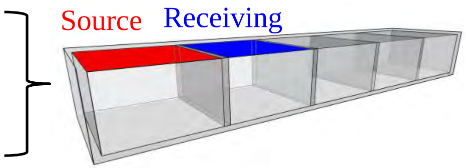
  (b) wave theory



Incorporating coupling parameters from junctions of finite plates inside SEA models: Adjacent plate

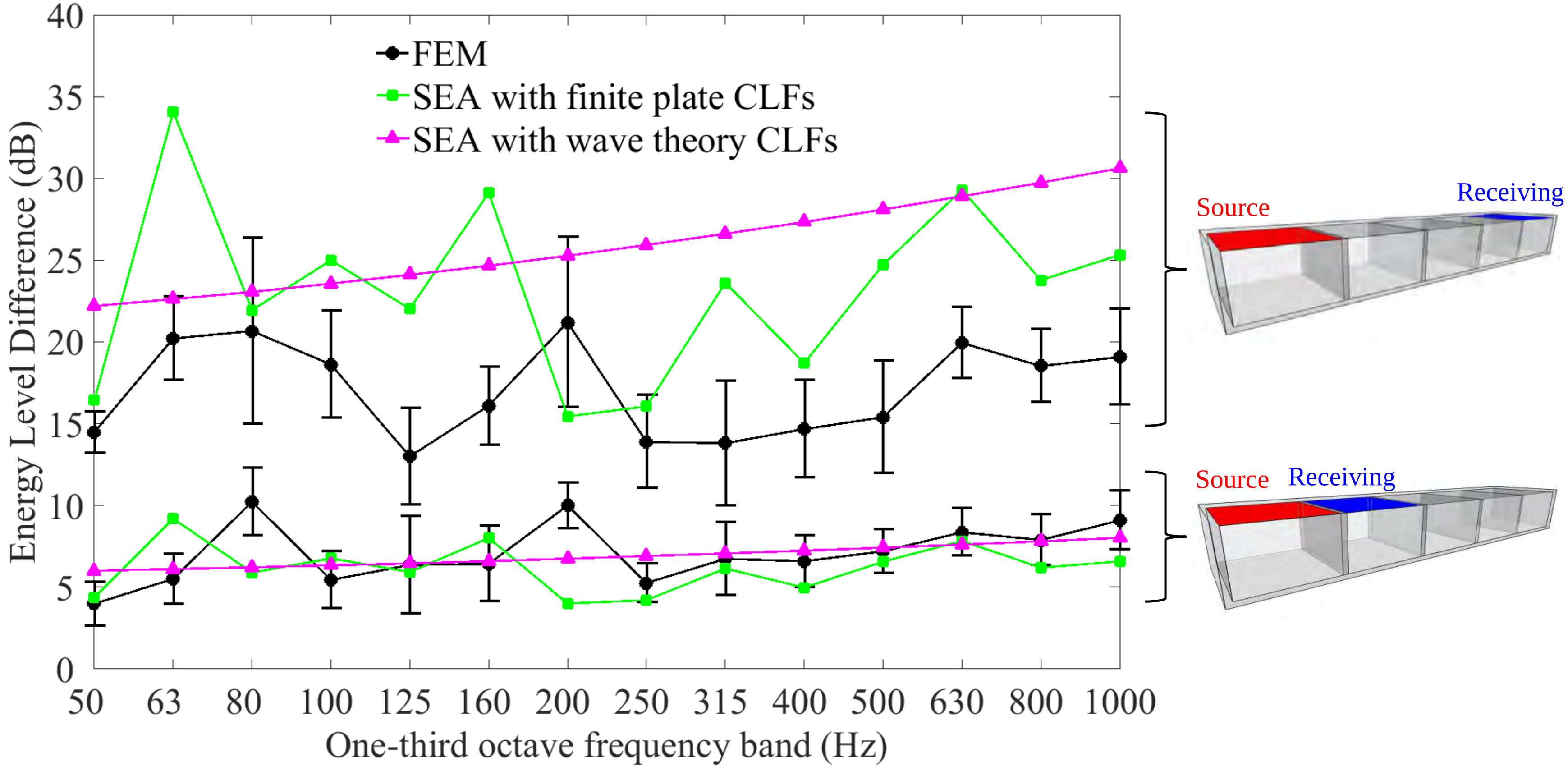
- When the receiving plate is directly connected to the source plate, both SEA models are close to the FEM ensemble average





Incorporating coupling parameters from junctions of finite plates inside SEA models: Non-adjacent plate

- When the receiving plate is far from the source plate, SEA using finite plate coupling loss factors only tends to improve estimates (compared to SEA with wave theory) above 200Hz

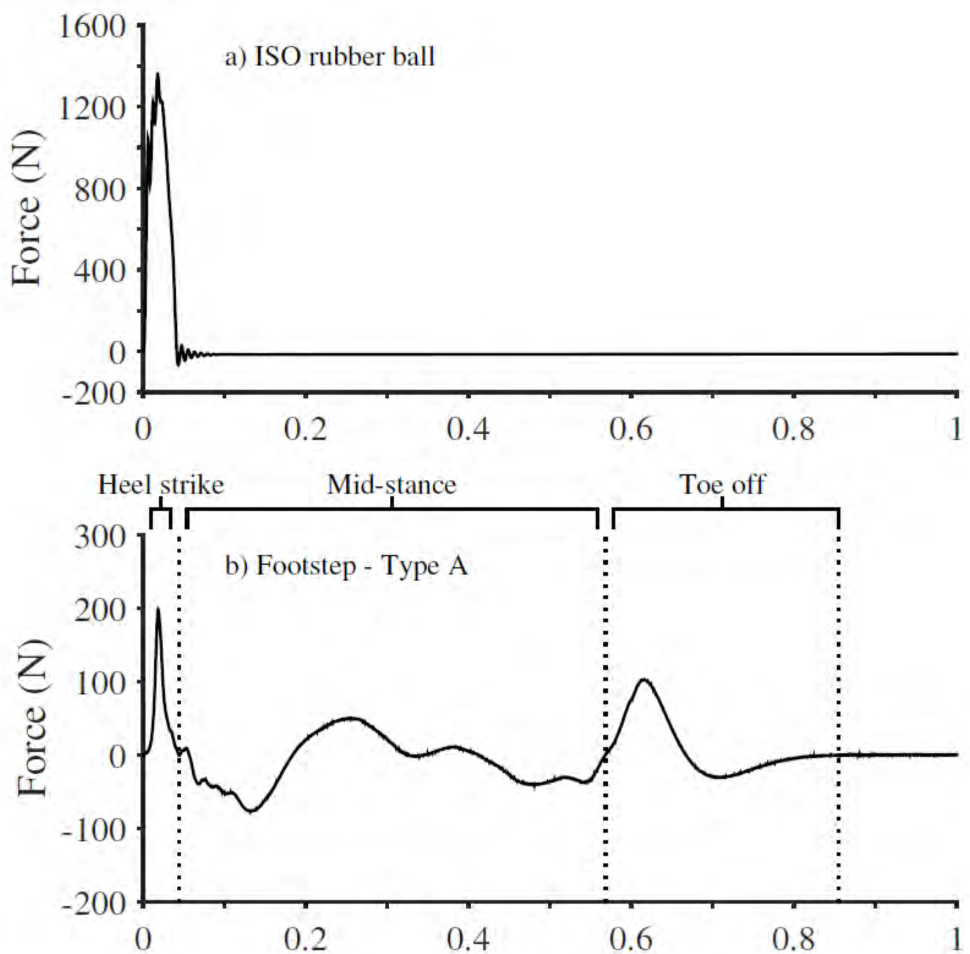


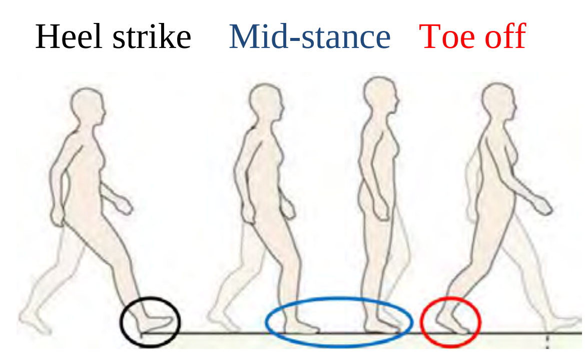
What else would be useful to know?

- When coupling parameters such as K_{ij} are measured or predicted for junctions of finite plates are incorporated in large sound transmission models (e.g. EN12354), any modal fluctuations in the transmission parameter (e.g. flanking sound reduction index) are unlikely to match those that occur in practice
  - Why not just quote an average coupling parameter measured according to ISO 10848 in the low-frequency range?

Can Fast time-weighted sound pressure levels be predicted for low-frequency impacts on floors such as footsteps?

Measured force applied by the rubber ball and footsteps



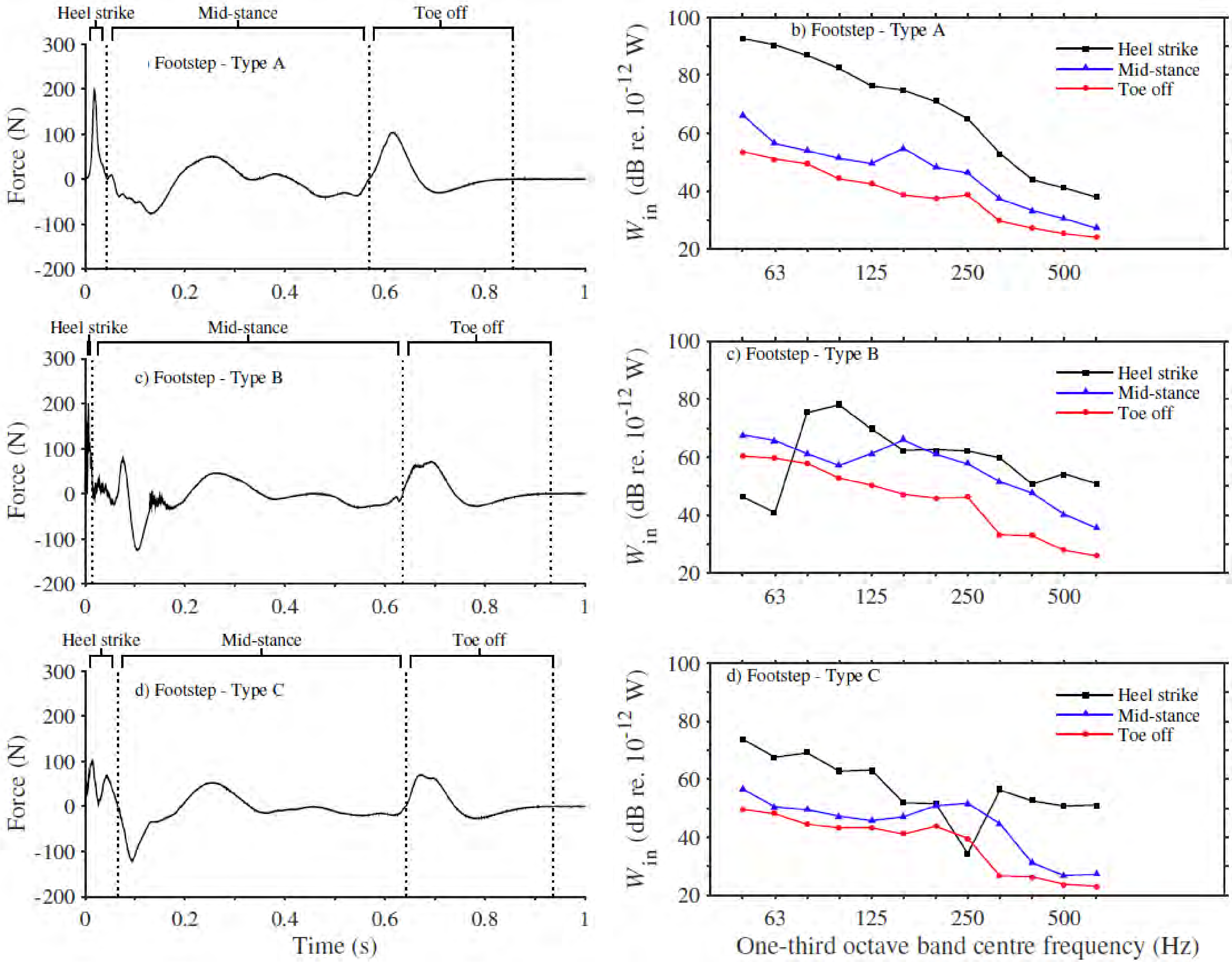


Single footstep – blocked force measurement

Type A:
Bare foot in a sock

Type B:
Hard-soled shoe

Type C:
Soft-soled shoe

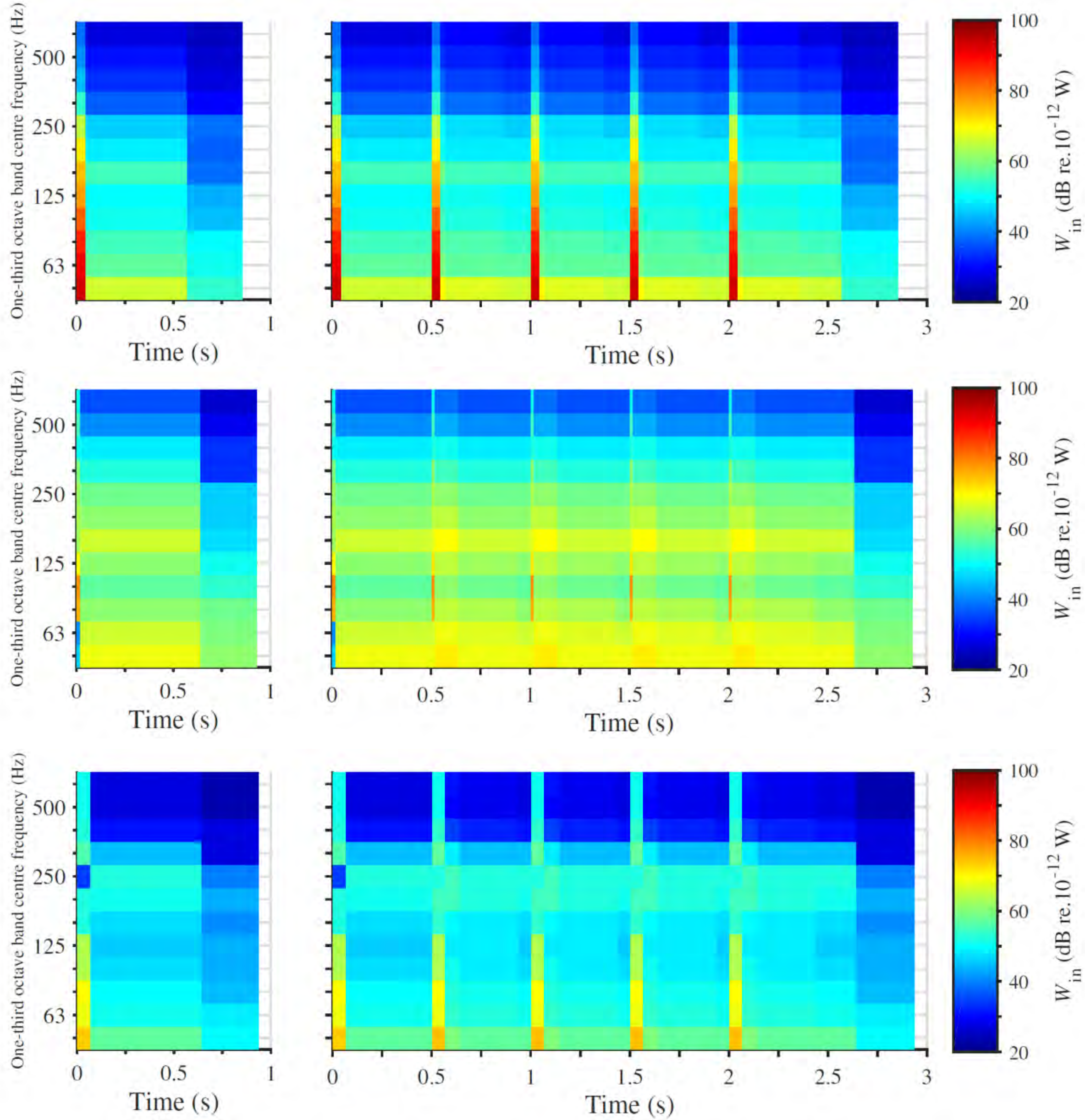


Transient power – single footstep and five footsteps

Type A: Bare feet in socks

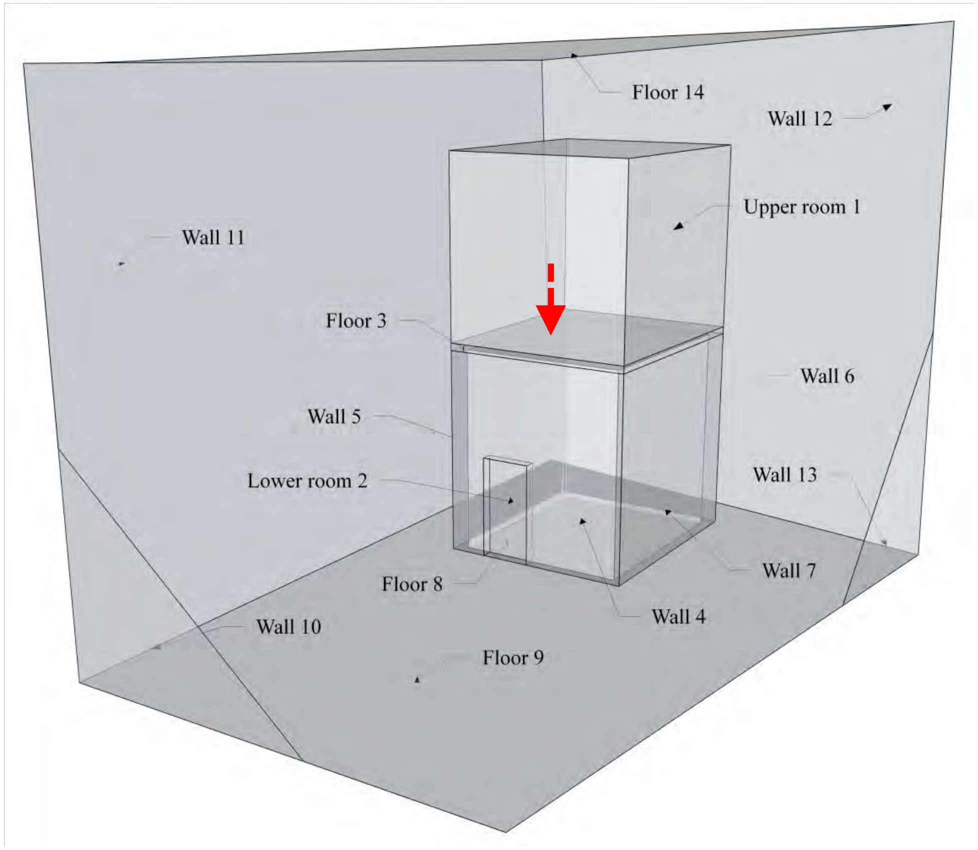
Type B: Hard-soled shoes

Type C: Soft-soled shoes

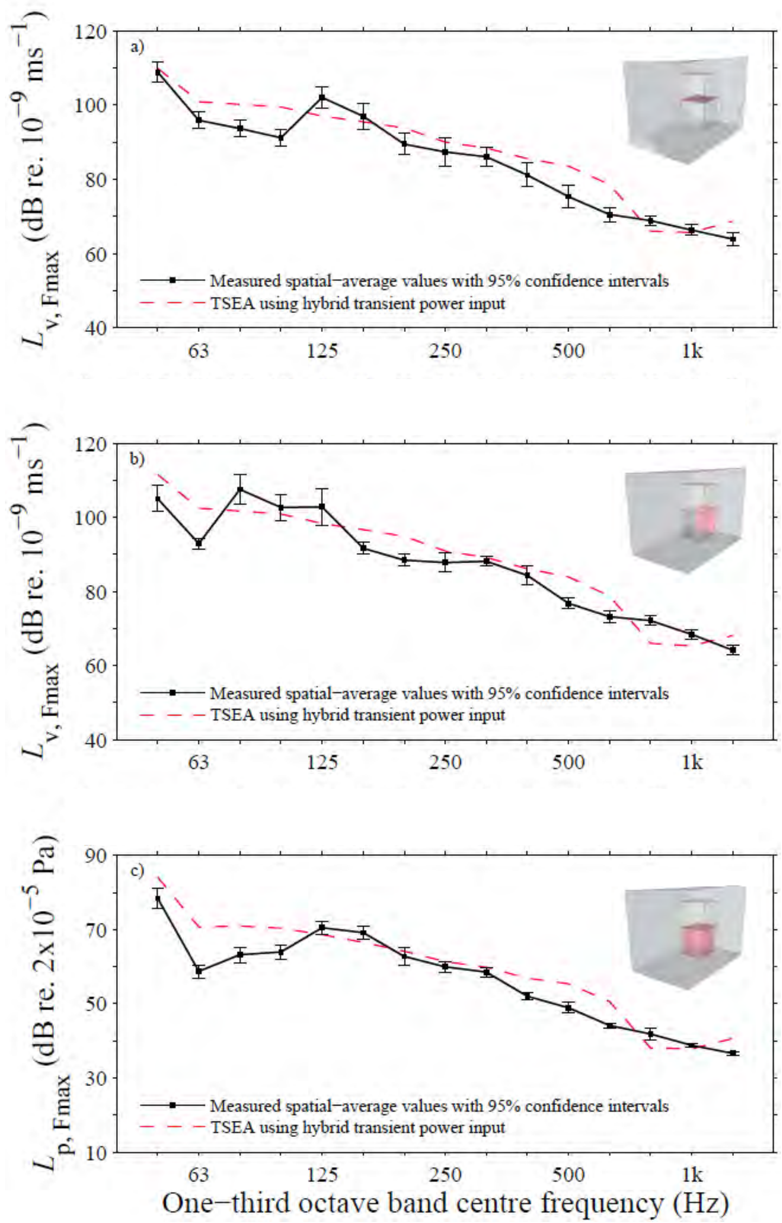


Experimental validation

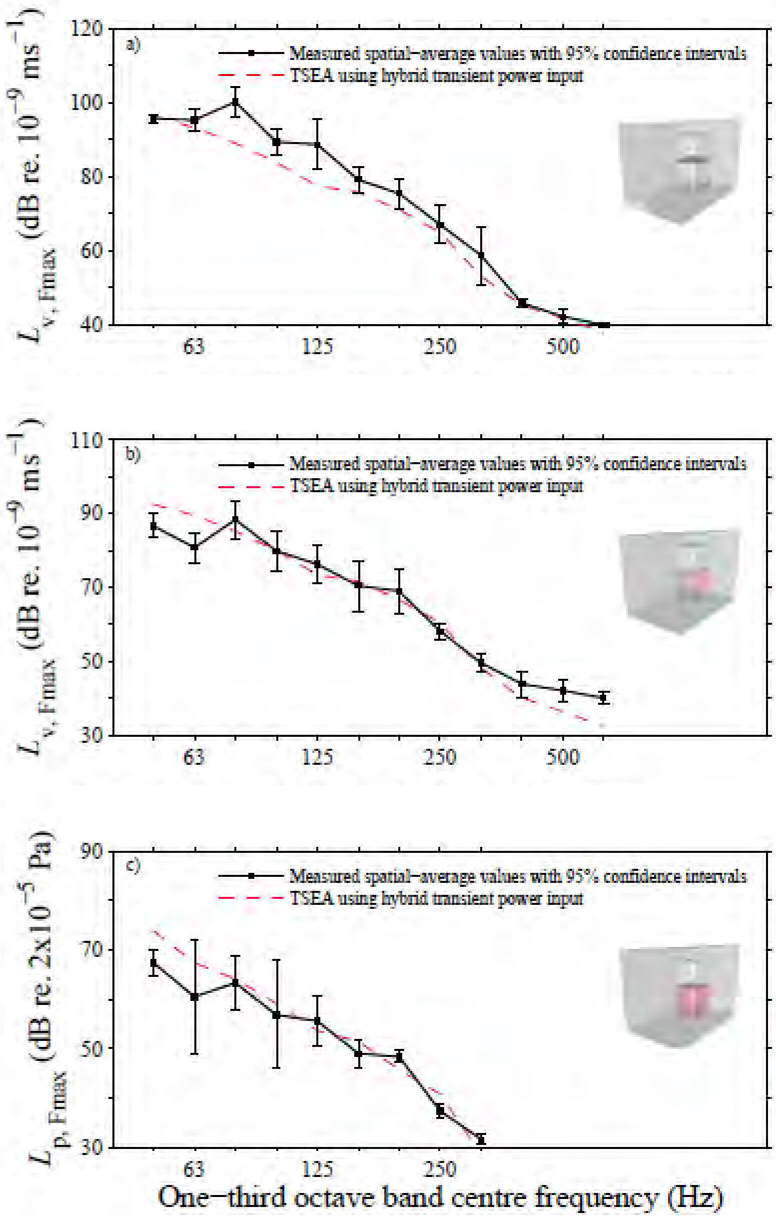
- Vertical transmission suite
  - Lower room is the receiving room ($V\approx50m^3$,$T\approx1.3s$)
  - Separated by ***140mm cast in situ concrete floor*** (4.6m x 3.9m)
  - Ground floor has 215mm ***heavyweight*** masonry walls with independent plasterboard linings
  - First floor has ***lightweight*** plasterboard walls



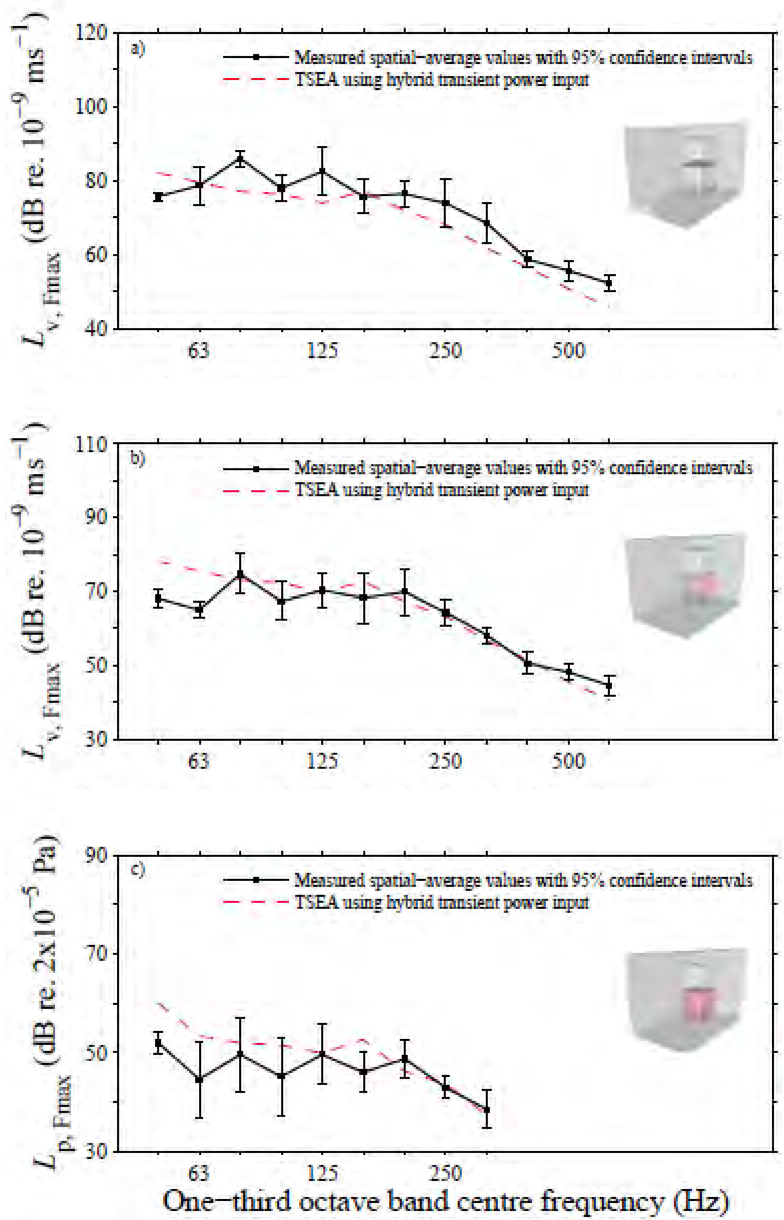
Comparison of TSEA with measurements: ISO rubber ball



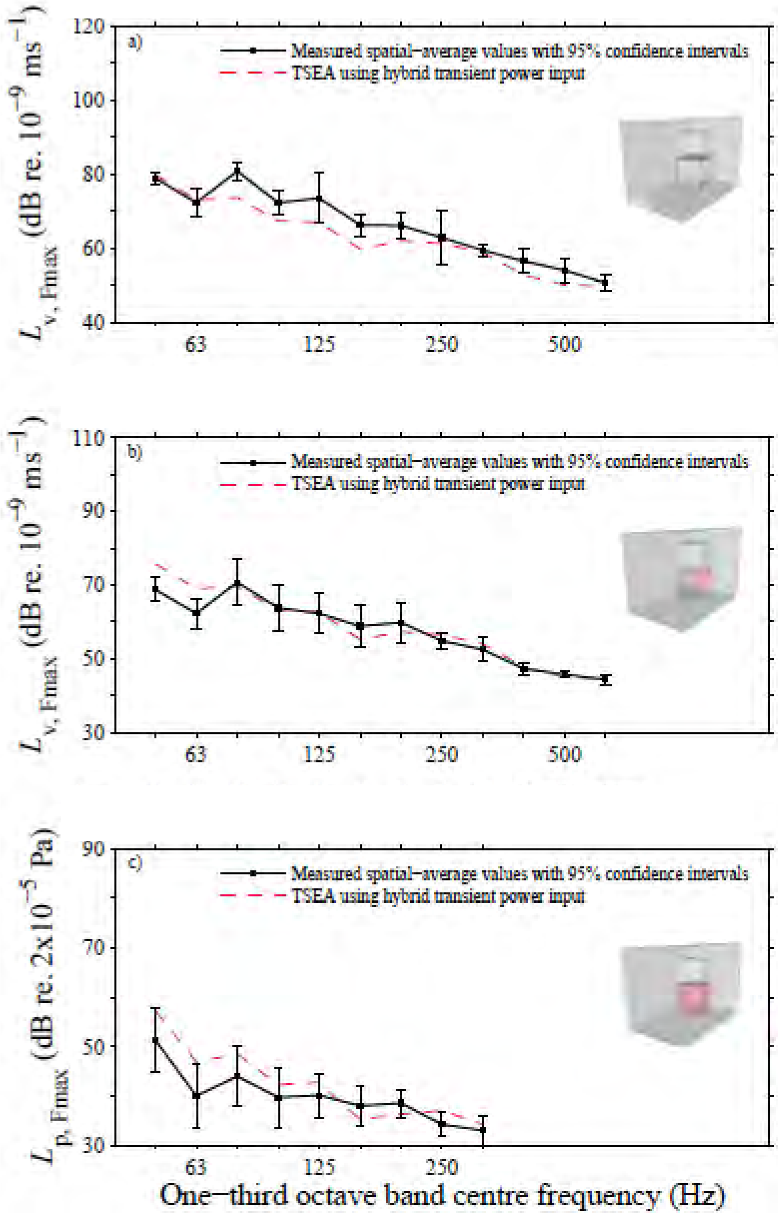
Comparison of TSEA with measurements:
Five footsteps: Type A - Bare feet in socks



Comparison of TSEA with measurements:
Five footsteps: Type B - Hard-soled shoes

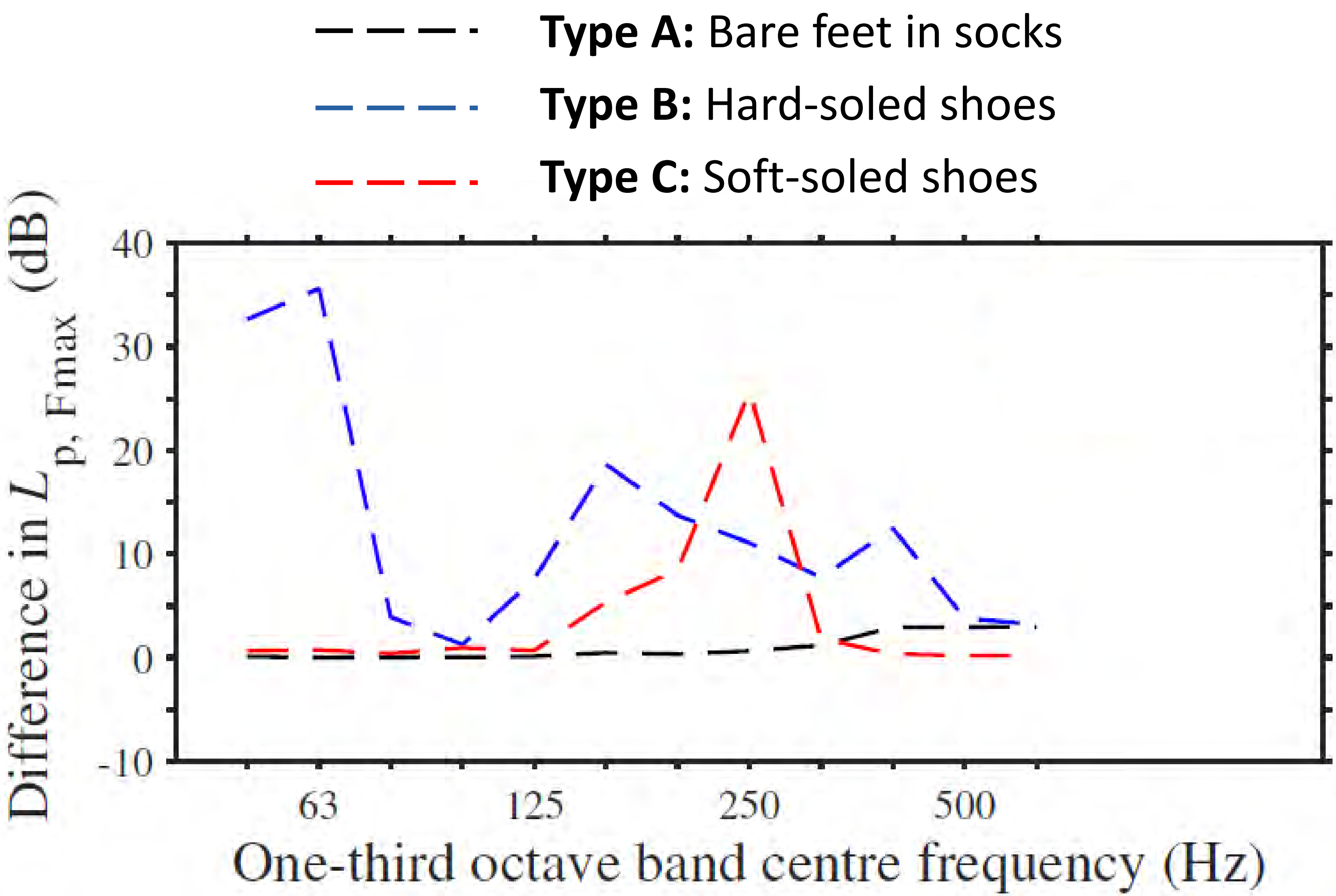


Comparison of TSEA with measurements:
Five footsteps: Type C - Soft-soled shoes



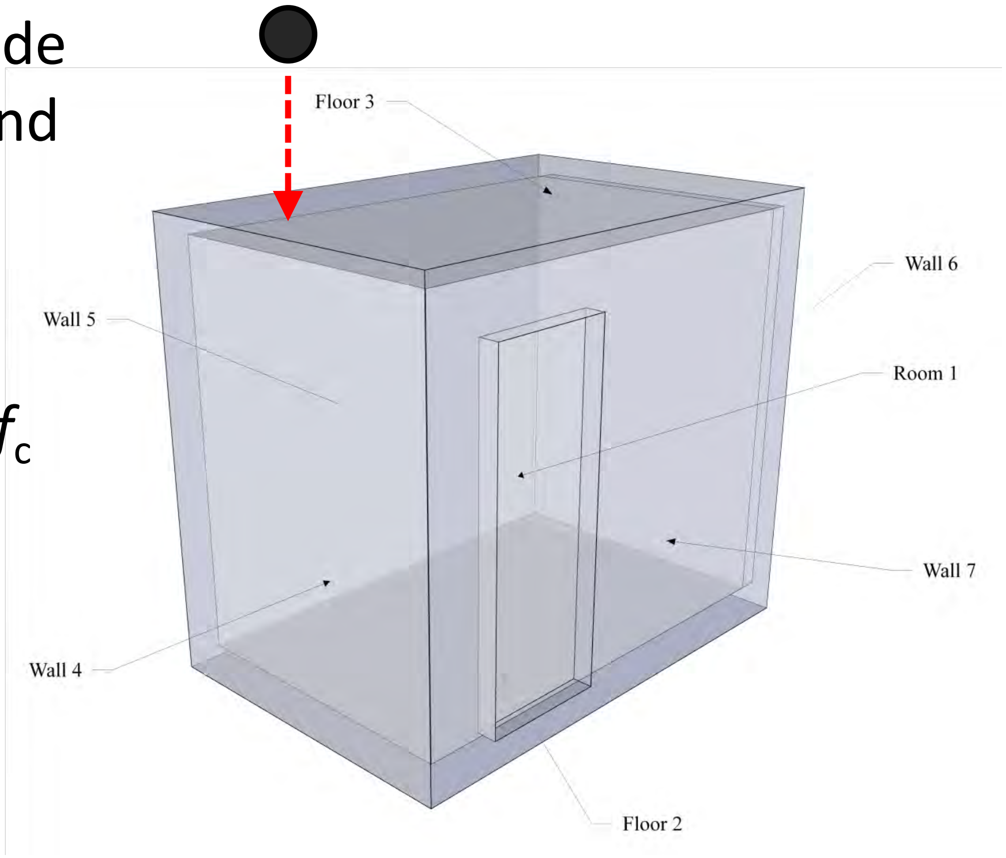
Is it possible to just consider the heel-strike?

- Difference between TSEA predictions using the heel strike instead of the combination of heel strike, mid-stance and toe-off

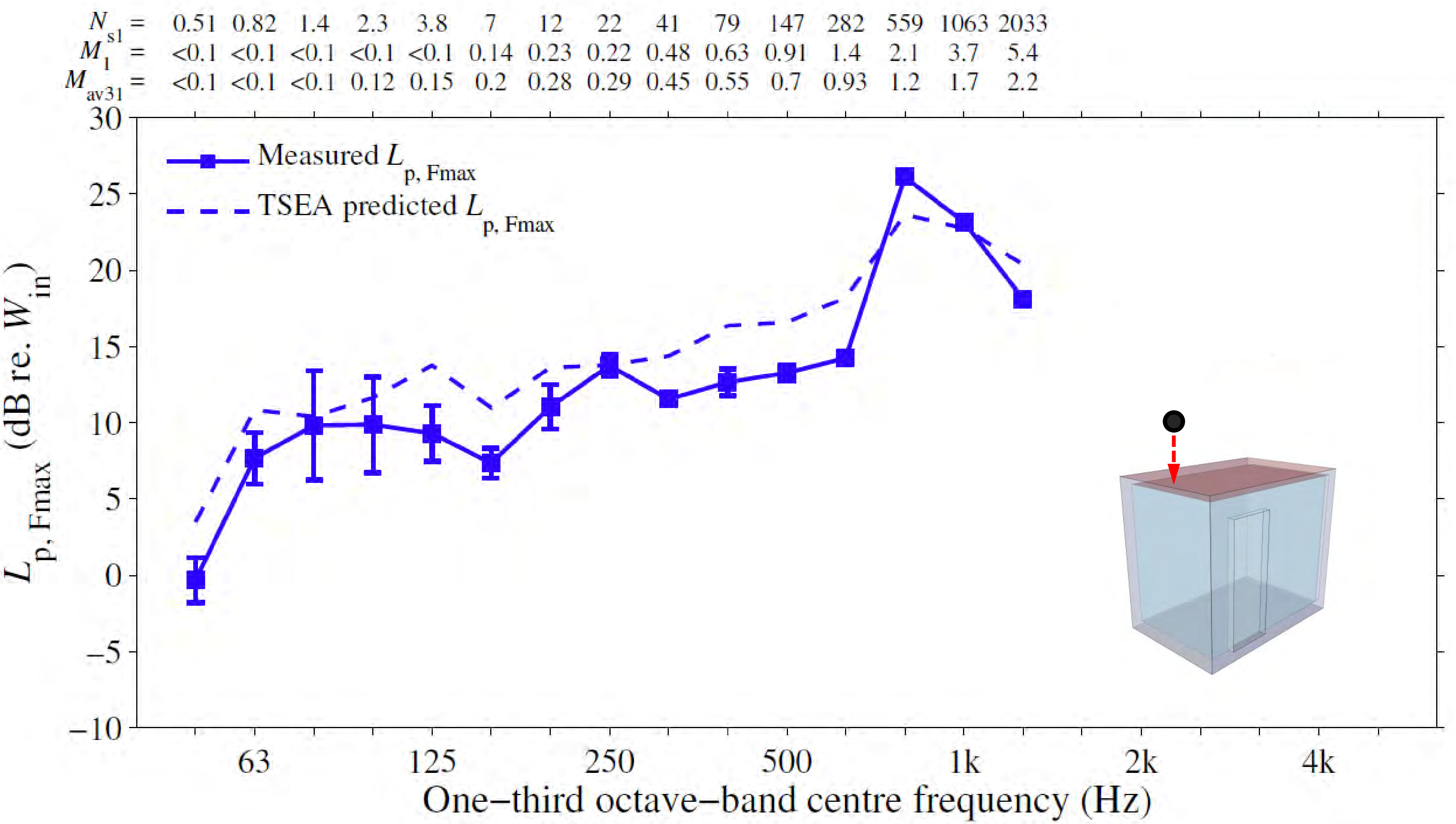


Experimental validation – Small building

- Isolated room ($V \approx 13 m^3$, T=2.8s to 4.1s)
- ***125mm concrete floor*** (2.8 x 1.8m) and ***heavyweight*** masonry walls
- All subsystems have ***low mode counts*** in the low-frequency range
  - For this reason a normal mode model for a coupled room and simply-supported plate was used to calculate radiation efficiencies for all walls and floors at frequencies below f_c



Results – Small building, Receiving room $L_{p,Fmax}$



What else would be useful to know?

- Does TSEA work equally well on more realistic heavyweight building structures with floating floors and ceilings?
  - Work is in progress to assess how can we quantify the ‘transient power’ when there is a floating floor on a heavyweight base floor
- Would TSEA work with lightweight buildings?
- Could we use the force plate to ‘standardise’ parameters for footsteps that could be used to give more insights into the pros and cons of rating methods and excitation sources (i.e. tapping machine, rubber ball and bang machine)?

Can transmission suites really give us low-frequency airborne sound insulation data that are useful at the design stage?

Transmission suite measurements of airborne sound insulation

- Reynders (JASA, 2014) shows that a probabilistic framework for prediction gives reasonable estimates of the (large) low-frequency uncertainty determined from Round Robin Tests

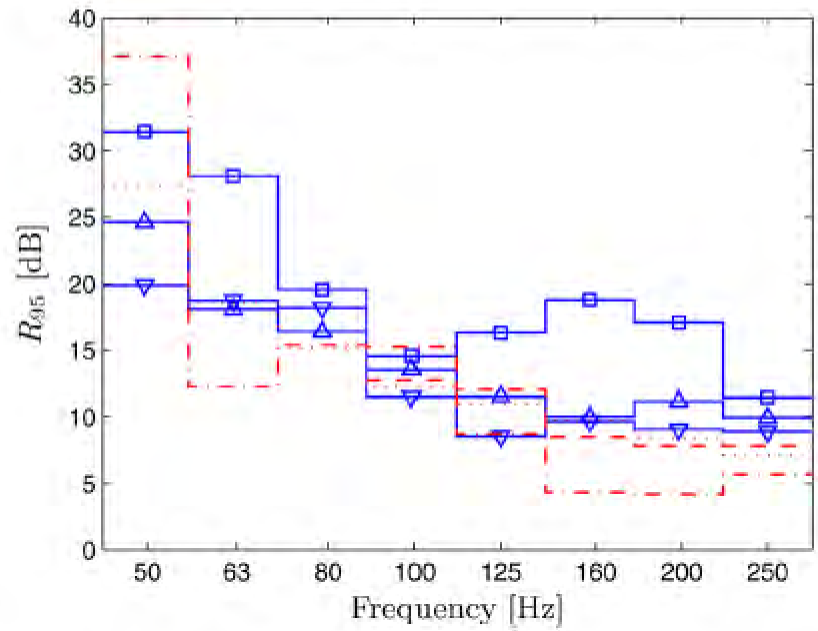
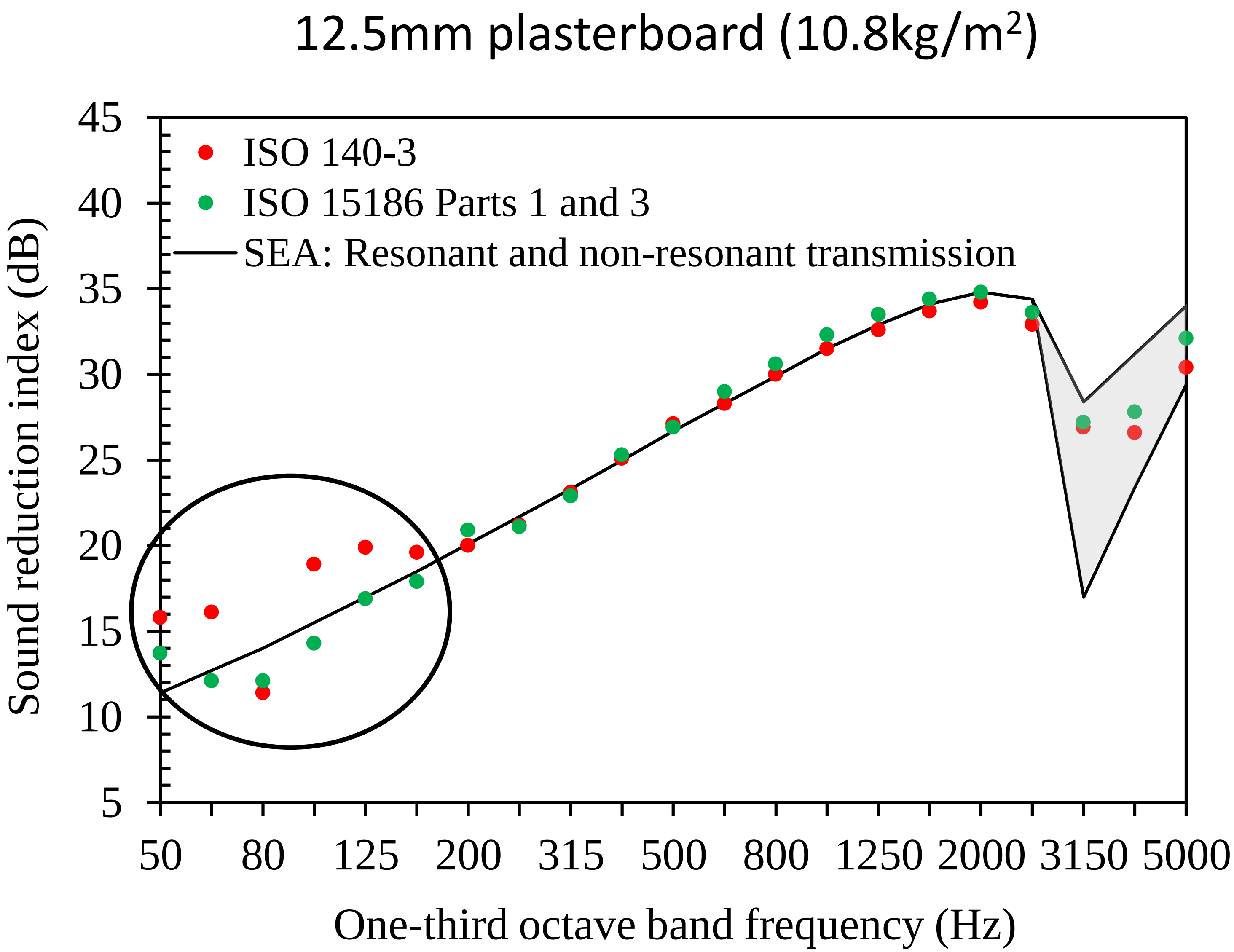
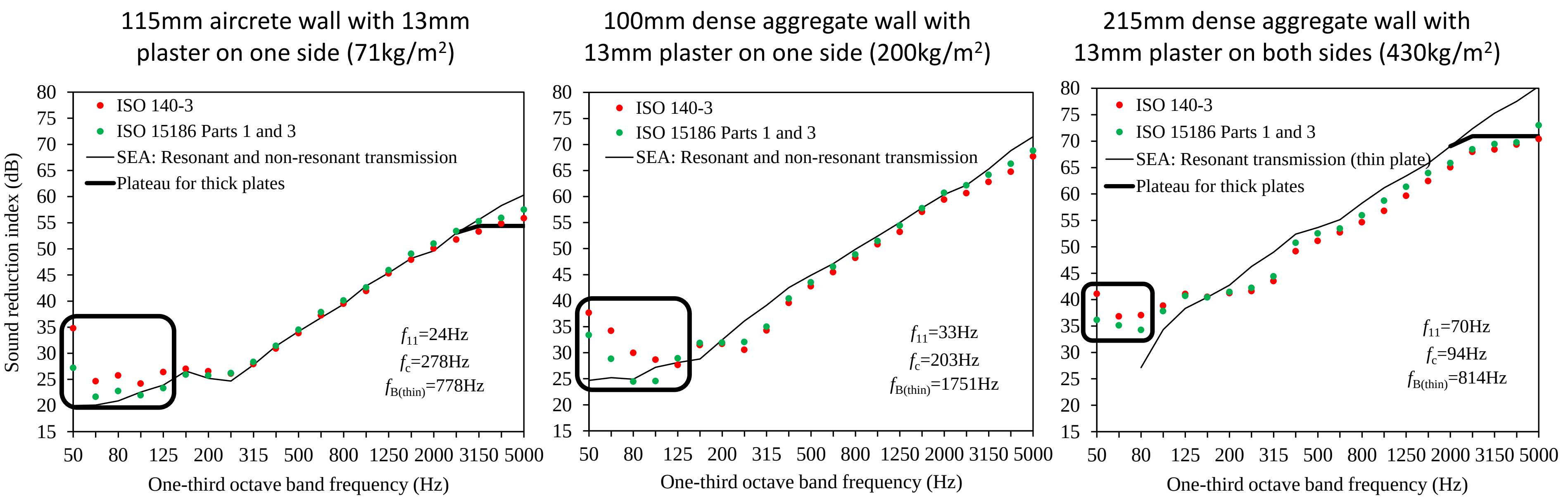


FIG. 9. (Color online) Ninety-five percent confidence interval of the predicted sound transmission loss of □ the calcium silicate block wall, Δ the gypsum block wall, and ∇ the double glazing. These are compared with the values corresponding to the reproducibility of inter-laboratory tests as listed in ISO 140-2 (Ref. 16) (dashed line), draft ISO 12999-1 (Ref. 18) (dotted line) and Hongisto *et al.*[17] (dashed-dotted line).

Transmission suite measurements
Comparison of ISO 10140 and ISO 15186



Transmission suite measurements
Comparison of ISO 10140 and ISO 15186

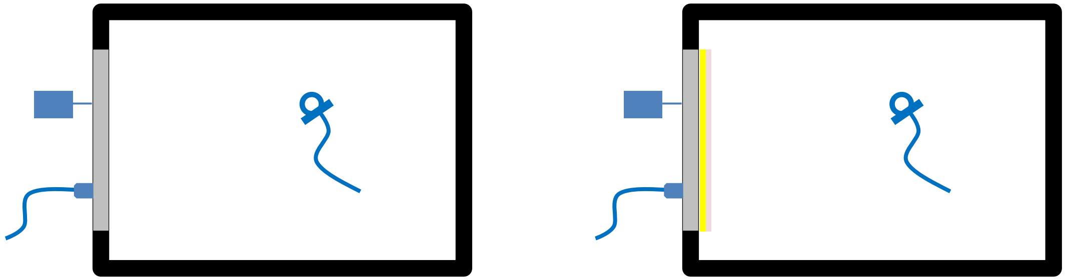


Transmission suite measurements
Sound reduction improvement index

- Wall linings tend to have their m-s-m resonance frequencies in the low-frequency range
- When including linings on flanking walls/floors in models (e.g. EN12354) it is only the resonant transmission that is relevant below the critical frequency of the base wall
  - Hence, $\Delta R_{\text{resonant}}$ is really the relevant quantity
- Use mechanical point excitation to give standardised transfer functions of sound pressure in the receiving room wall/floor vibration

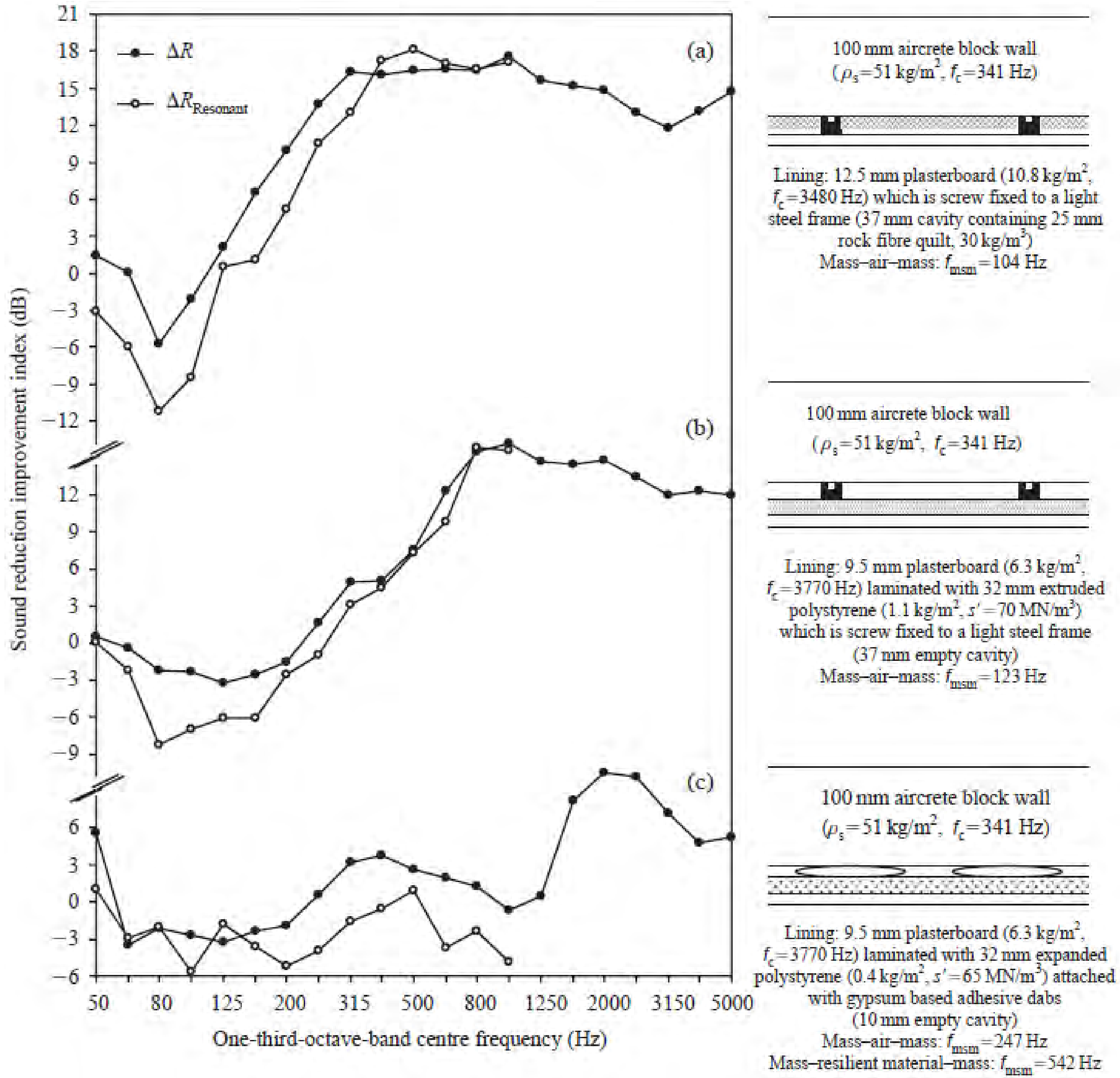
$$L_{\text{pv},T} = \left\{ \frac{1}{M} \sum_{m=1}^{M} \left[\left(10\lg\left(\frac{1}{NR} \sum_{r=1}^{NR} 10^{L_{\text{p},r}/10} \right) \right)_m - \left(10\lg\left(\frac{1}{N} \sum_{n=1}^{N} 10^{L_{\text{v},n}/10} \right) \right)_m \right] \right\} - 10\lg\left(\frac{T}{T_0} \right)$$

$$\Delta R_{\text{resonant}} = L_{\text{p,v},T\text{(without lining)}} - L_{\text{p,v},T\text{(with lining)}}$$



Transmission suite measurements
Sound reduction improvement index

- Mechanical excitation tends to emphasize the dip at the mass–spring–mass resonance
- Relevant to point force excitation such as with impacts on walls and floors, or some types of machinery/equipment
- However, highly negative values at the resonance frequency are not always observed when a flanking wall/floor is excited along its boundaries by structure-borne sound waves transmitted from other connected plates



What else would be useful to know?

- Could a large Round Robin involving a systematic comparison of airborne and impact sound insulation using ISO 10140 and 15186 allow guidance to be developed on which laboratories could quote results below 100Hz?
  - For example, if ISO 10140 and ISO 15186-3 data were within *X*dB for 50, 63 and 80Hz bands and a certain type of element, then either method could be quoted by the laboratory. If not, those laboratories would measure the 50, 63 and 80Hz one-third octave bands but only quote a value calculated for the 63Hz octave band.
- Whilst ISO 15186-3 allows a *fairer* comparison of the low-frequency performance of wall/floor products, does it really improve the accuracy of predicted sound insulation in the field when incorporated into models such as EN ISO 12354?
  - Unlikely because the Waterhouse correction is such an inaccurate correction in small rooms
- When $\Delta R_{\text{resonant}}$ is incorporated on flanking walls/floors in large sound transmission models (e.g. EN12354), does it actually improvement agreement with the measured sound insulation?

Moving forward, how might we more effectively bring together research on subjective evaluation, rating, measurement and prediction of low-frequency sound insulation?

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