Accuracy and Purpose of Building Insulation Measurements

George Dodd[1], Gian Schmid[2] and Daniel Martens[1]

(1) Acoustics Testing Centre School of Architecture & Planning, NICAI Faculty, University of Auckland, Auckland 1010, New Zealand

(2) Acoustics Testing Service, University of Auckland, Auckland 1010, New Zealand

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Abstract

In view of the imminent publication/adoption of a revised and expanded section G6 of the NZBC it is timely to consider how accurately we can confirm the acoustical performance of buildings by objective measurement. An obvious extension of this is to consider how our measurements (and their associated accuracy) match up with our ability to subjectively detect changes in the quality of building insulation. This has implications for how we might advance from a concept of a simple pass/fail for buildings based on a minimum building performance (i.e. specified in G6) to a set of categories of acoustic comfort for guiding both designers and (with reliable verification) prospective occupiers. In research to develop techniques for screening the performance of buildings we consider the possibility of measuring the impact insulation of floors by an alternative to the standard tapping machine plus a full ISO 10140 procedure. The success of such techniques depends on the saving in measurement effort and the increase in uncertainty they involve.

INTRODUCTION

The workshop on the proposal for revising section G6 of the NZBC has set a default theme for this conference and in this paper we report on developments in international standards and in our own research concerning the measurement of insulation in buildings with particular focus on the implications of the uncertainty of these measurements.

This is particularly topical in view of the recently issued draft international standard ISO/DIS 12999 -Determination and application of measurement uncertainties in building acoustics [1] which requires NZ's vote for acceptance or rejection by October this year. In the first part of the presentation we consider the main content of this draft, what understanding is needed and its implications for measurements in NZ.

In a second part we look to beyond the enacting of a revised G6 to putting in place a rating system for the acoustical performance of dwellings -as exists in several countries -variously termed Categories of Acoustic Comfort, Acoustic Quality Rating or simply Sound Classifications. These will provide descriptions and goals for higher performance than the minimum legally acceptable specified in G6.

Finally we present interim results from part of a project aimed at developing screening techniques for checking the sound insulation in buildings. Such tools would be valuable for quality assurance programmes and -depending on their precision -as economic means for certifying building performance. In this case we describe a possible alternative to the standard tapping machine for making impact insulation measurements. All three parts in the presentation can be seen to linked via the need for confidence in the measurement results

MEASUREMENT UNCERTAINTY IN SOUND INSULATION

The University of Salford 2001 report on Uncertainties in Noise Measurement [2] begins with the following "Measurement uncertainties tend to be either ignored or, at best, politely alluded to by practical scientists and engineers. This is because they have usually been frightened off by what has in the past been portrayed as a somewhat imperfect science made quite complex by sophisticated statistical mathematics"

For the ordinary practitioner it is perhaps made more complex by the initial hurdle of grasping the terminology used. In some cases this is familiar from everyday language but which now has quite specific and non-intuitive technical meanings. Then there are new terms to embrace as well.

It is evident that many of the revisions of the ISO standards that govern the measurements we make are moving to require our measurement results to include statements of uncertainty. So it is clear that 'polite allusion' is no longer acceptable. Understanding of uncertainty is needed if we are to be confident in providing meaningful and dependable uncertainty statements with our measurement results (both from the laboratory and from the field).

Anyone who wishes to engage with these issues (and, importantly, provide input on how NZ should vote on the draft international standard) is encouraged to read ISO/DIS 12999 [1] but it will not be an easy read. We recommend as an excellent tutor on the subject Kirkup and Frenkel's book An Introduction to Uncertainty in Measurement using the GUM (Guide to the Expression of Uncertainty in Measurement) which is available as a Cambridge on-line book [1]

The following are a selection of the most important terms used in metrology and uncertainty discussions MEASUREMENT:

We colloquially use 'measurement' to mean a numerical value or result but in metrology it is the process of obtaining the value or result. Instead we must be strict about using the terms Measurand and Measurement result

MEASURAND: This is the quantity that is being measured e.g. Sound Reduction Index, R_T, D_{nTw}.

MEASURMENT RESULT: The measured value of a measurand.

ESTIMATE; BEST ESTIMATE: We are unable ever to find the true value of a quantity through measurement (because of errors -see below). What we find from our measurement is an estimate of the true value. Provided that the variation in our measurement results is the result of random sources then the mean of our results constitutes the best estimate of the true value.

ERROR: In everyday usage the import of this is that it is a mistake or a blunder but in metrology it is simply the difference between a valid measurement result and the true value -Error = (Measured value -True value)

ACCURACY: Is a comment on how close we believe a measured value is to the true value (which is, in principle, unknowable) and is quite different from precision.

PRECISION: This is a comment on the likely variability in our results. If, when we make repeat measurements the results show little variation then the values are described as being precise.

UNCERTAINTY: Since errors are unavoidable components of the measurement process their net effect is uncertainty in the value we obtain for a measurand. This uncertainty is given quantitatively as an interval around the best estimate we obtain which (we hope) we are confident (to a stated level) will contain the true value of the measurand. Two versions for uncertainty are referred to in GUM [3] STANDARD

UNCERTAINTY: (Symbol 'u' -lower case).This is merely the standard deviation of our repeated measurement results.

EXPANDED UNCERTAINTY: (Symbol 'U' -upper case) -is the standard uncertainty multiplied by a factor (termed the coverage factor) to expand the interval around the best estimate for containing the true value with greater confidence. The coverage factor (based on the population probability distribution and degrees of freedom in the results) is chosen to give the level of confidence required. For example this might be 95% (i.e. 95 times out of 100 repeats of obtaining estimates this interval round the estimate will include the true value). ISO/DIS 12999 gives values for coverage factors assuming the total errors are Gaussian distributed.

REPEATABILITY AND REPEATABILITY CONDITIONS: Repeatability uncertainty refers to the amount by which measurement results vary when the measurements are repeated with -as far as possible -nothing changing. So, either in the laboratory or for a field test, it means carrying out a sequence of measurements by following closely the same procedure each time (i.e. same transducer positions, undisturbed sample, same source and environmental conditions etc.). ISO/DIS 12999 describes these measurements as being made under repeatability conditions. (Note, the standard also refers to this as Test Situation C)

REPRODUCIBILITY AND REPRODUCIBILITY CONDITIONS: When results need to be compared which come from different locations (measured by different measurers using different equipment and detailed procedures) but on the same, or nominally the same, measurand then the results are described as being obtained under reproducibility conditions and the and the uncertainty is the reproducibility uncertainty.

When the locations are test laboratories which meet the requirements specified in the relevant part of ISO 10140 [4] this is referred to as Test Situation A. The uncertainties in this case are, for example, what would be applicable if comparing the results from the same sample tested by the Acoustics Testing Service in Auckland and by the Engineering Dept at Canterbury University.

IN-SITU CONDITION / TEST SITUATION B: A third situation is described in ISO/DIS 12999 (referred to as an In-Situ condition and also as Test Situation B) which has particular relevance for field measurements. This is where the same item (e.g. wall, or whole building) has repeat measurements made but by different measurement teams. The resulting in-situ uncertainties would be expected to describe the spread of values (i.e. include the differences) that we might expect if in a field verification of a building performance value e.g. $D_{nT,w}$, were carried out by different consultant members of the Acoustical Society of New Zealand!

LABORATORY AND FIELD MEASUREMENT UNCERTAINTIES: The main thrust of ISO/DIS 12999 seems to be to encourage laboratories to closely monitor their repeatability uncertainties and to promote inter-lab comparisons (Round Robin tests) for establishing reproducibility uncertainties.

With only two ISO complying labs in NZ we do not have the minimum number (i.e. 8) required by ISO/DIS 12999 to undertake an inter-lab comparison. In this case the standard gives default values for the reproducibility uncertainties (see Table 1, Situation A) which are mandatory to be used. We can verify that the Acoustics Testing Service does meet the 1/3 octave repeatability requirements (Situation C) and, in the absence of testing to show otherwise we, as required, will apply the Situation A values as 'expected reproducibility uncertainties'.

However it is important to understand that these uncertainties only indicate a range for the differences found between labs when measuring an identical specimen. The variations that might appear in the performance results when different custom built samples of the same nominal construction are tested almost certainly will span a greater range!

This becomes an important concern if, say, for certification purposes an Rw value is obtained from a single, very carefully constructed sample in the laboratory. We might expect that other samples constructed under less carefully controlled conditions could exhibit results which are poorer by important amounts. Therefore if producers of wall systems and/or builders wish to have a good degree security about meeting a specified performance they will need knowledge of reproducibility uncertainties for their range of constructions and systems. Then they can select a system to build which has its best estimate of performance exceeding the performance requirement by the amount of the reproducibility uncertainty.

A similar approach is required by ISO/DIS 12999 when carrying out field measurements to verify that a building component or whole building meets a performance requirement. If, for example, we have a performance requirement of $D_{nT,w}$ = 60 then it is mandatory for the measured result to exceed 60 by the amount of the expanded uncertainty:

$$D_{nT,w} > 60 + U \tag{1}$$

Ideally, U would be found by making sufficient repeat measurements in the building to obtain a reliable estimate of their standard deviation, u, which when multiplied by the relevant coverage factor (e.g. K = 1.6 for 95% confidence -one sided test!) leads to the value for U so:

$$D_{nT,w} > 60 + 1.6u \tag{2}$$

Of course repeated measurements require more time and expense so if only a single measurement is made for economy reasons then the standard provides mandatory default values for u. In the case of the $D_{nT,w}$ = 60 example u = 0.8 (see Table 1). This means that the minimum value required for conformity to be demonstrated (with 95% confidence) is:

$$\begin{aligned} D_{nT,w} &= 60 + 1.6x0.8 \\ &= 61.3. \end{aligned} \tag{3}$$

It is worth emphasizing again that this only indicates the acceptability of that one specific building or construction and not other nominally similar items. But by performing repeat measurements on a selection of nominally similar constructions reproducibility uncertainties could be determined which then could be used to to assess the confidence that a whole family of similar constructions (e.g. an apartment block of replicated units) will meet the performance requirement.

It is worth noting that ISO/DIS 12999 quotes values of dB quantities to 0.1 dB. By implication this is the amount by which buildings could either pass or fail code requirements if this standard is adopted as an 'acceptable solution' for a verification method in G6.

A further development in standards that has implications for measurement uncertainties is the proposed ISO 16717 (see Scholl et al [5]). This is suggested to eventually replace the present ISO 717 which specifies the procedures for processing and expressing insulation performance into single figure ratings. In ISO 16717 we find strong support for extending our formal measurement range down to 50 Hz, the removal of spectrum adaptation terms in favour of separate R values for different source sounds, and the replacement of $L_{n,w}$ for impact sound by a new R value (R_{impact}) analogous in concept to airborne R values. (We might wonder if even this is low enough given the power radiated by woofers and sub-woofers used in home entertainment systems and also given that the question of our sensitivity to the infrasound created by people movement in lightweight buildings remains un-researched.)

CATEGORIES FOR HIGHER PERFORMANCE THAN G6

Since the requirements specified in G6 have their basis in the protection of health they constitute a minimum performance unlikely to be adequate for complete protection of the amenity of dwellings. Both the German Society of Engineers (VDI) [6] and the Association of Australian Acoustical Consultants [7] provide tables which illustrate this inadequacy well (see, for example, the first column in Table [1] from [6])

Table 1: Perception of customary noises from neighbouring dwellings and assignment to three sound insulation classes (SSt)

Column	1	2	3	4
Row	Type of noise	Perception of the emission from the neighbouring dwelling, typical evening background noise level of 20dB(A) and customary large living spaces assumed		
1		SSt I	SSt II	SSt III
2	Loud speech	intelligible	in general intelligible	in general not intelligible
3	Raised speech	in general intelligible	in general not intelligible	not intelligible
4	Normal speech	in general not intelligible	not intelligible	not audible
5	Walking noise	in general disturbing	in general not disturbing	not disturbing
6	Noise from building service installations	unreasonable annoyances are in general avoided	occasionally disturbing	not or only seldom disturbing
7	Music, loudly adjusted broadcasting and television equipment, parties	clearly audible		in general audible

It was proposed by members from the committee considering the revision of G6 that when this revision was completed the next stage should be the development of a hierarchy of improved levels of performance similar to the systems adopted in overseas countries (see Rasmussen[8]for a review).

It is clear from the increasing number of complaints about noise being registered by local authorities in NZ (e.g. complaint figures for greater Auckland show a rise from 45,80pa to 54,000pa in the last 3 years) that there are groups of people who are not being adequately protected. Some of these will be cases where the buildings do not meet G6 requirements but it is safe to assume that the increase is being driven largely by occupants of the new higher density developments which we must assume do meet G6.

In developing these higher performance categories we suggest that among the issues to be considered are:

- How many categories are needed
- What range should these cover
- What measures should be included
- Should we harmonise with overseas trends
- Do we need to formally establish norms for acceptable behaviours in different dwelling types?

Our thoughts are that we should try to approach these issues initially without being unduly influenced by what's happening overseas. A starting point is to consider the number of levels, or categories, of performance that are desirable. It seems appropriate that this number should accord with any innate categorical sense that we possess. So we must determine whether or not we "feel" or intuit a certain number of subjective divisions (i.e. categories) for ranges.

There are numerous examples in life where we use 3 main divisions, e.g. A,B and C for grading exam papers; Hot, Warm and Cold for water or weather temperatures; Tall, Average and

Short for heights; Child, Youth and Adult for ages; Primary, Secondary and Tertiary for educational establishments; Gold, Silver and Bronze for Olympic winners; (there are even examples from the field of local acoustics: Reasonable, Unreasonable and Excessive for noise severities in the RMA; Good, Better and Best for advertising wall system performances). Of course when required -primarily when numerical need demands -we can divide these further (e.g. for grading we have A+, A and A- etc; Baby , toddler and Infant for Children).

An area we can look to for guidance here is the discipline of Human Geography. In foundational work by Edward Hall ('Man's (sic) use of space in public and private' [8]) it is interesting to note that he suggests that we sense 4 categories for our distance from other i.e. intimate, personal, social and public. On the other hand in situations where star ratings are used it is usual to use up to a maximum of 5 stars.

Whilst this issue merits further research we sense that an appropriate number for levels or categories is in the 3 -5 range. This is what we find in overseas rating systems e.g. Germany has 3 'Classes of Acoustical Comfort' whilst Australia has a 5 tier 'Acoustic Rating' system.

Next in importance is to decide what quantities we want to "rate" and what the extremes of performance should be. Two main approaches are evident overseas which are 1) rating performance by the percentage of people 'annoyed' or 'disturbed', as in Scandinavia, and 2) audibility of sounds, as in Germany and Australia. However, we suggest that audibility of sound is the more appropriate basis for rating dwellings as this more directly links with privacy . What most distinguishes dwellings from other buildings is that their amenities should be private.

Hence we suggest that the bottom and top categories of a New Zealand rating system should be 1) the performance legislated in the Building Code and 2) performance which provides Acoustic Privacy, respectively. Our definition for Acoustic Privacy is that condition where no information about your or your neighbour (including your or their presence) is communicated by sound.

Whether or not we can hear a sound through a party wall not only depends on the insulation it provides but also on the strength and type of sound incident, therefore a 'privacy' approach will require that we consider establishing norms for what is normal and acceptable behaviour in dwellings which have neighbours. It is logically possible to define different qualities of housing stock based on what constraints are necessary to be imposed on dwellers in order to ensure Acoustic Privacy.

We suggest that a committee be established to begin drafting a New Zealand system of performance categories and that the matters outlined above are a suitable starting point for its deliberations.

AN ALTERNATE METHOD FOR RATING THE IMPACT SOUND INSULATION OF FLOORING

One of the main factors limiting measurements of normalised impact sound level is the fixed amount of power delivered to the floor by the hammers. The hammers have a specified drop height, repetition rate, mass and surface area to deliver the impact. This limits the sound pressure level radiated from the floor in the receiving room; in a noisy environment this can make field measurements difficult or even impossible. However, no such limitations exist for measuring the sound reduction index; in a noisy environment you need only increase the volume output of the airborne source or use a synchronous averaging technique.

Making a normalised impact sound level measurement also requires you to occupy two locations at once, both in a transmitting room and in a receiving room. A large amount of heavy and expensive equipment is needed, which in field testing poses a significant deterrent. Other factors that also add to the difficulty of field measurements, include testing on delicate surfaces, such as tiled floors, which can risk damage to property.

As the transmission of airborne sound and impact sound are governed by many of the same mechanical and vibrational properties it is logical that a relationship should exist between them. It is well established that such a relationship does exist and this was shown for a general floor situation by Heckl & Rathe[9] and later developed by Vér[10].

We propose a method of rating the impact insulation of a floor using the readily available airborne sound measurement of the sound reduction index, the theoretical relationship shown to exist between the normalised impact sound level and sound reduction index and an adjustment to the normalised impact sound level from the impulse response of the floor. Accelerometers attached to an International Authority for Standardisation (ISO) standard tapping machine hammer[11] will be used to find the improvement in normalised impact sound level for different surface coverings.

THEORETICAL BACKGROUND

Using a reciprocity method Heckl & Rathe[9] derived a general relationship between the normalised impact sound level (L_n) and sound reduction index (R) as follows:

$$L_n + R = 10\log\left(\frac{k^2 F_T^2}{4\pi A_0 p_0^2}\right) \quad (4)$$

where k = 2π/λ is the wavenumber in air, FT is the periodic impact force of the hammer (with the time period between impacts being T), A_0 = 10m^2 is the normalised room absorption and p_0 is the reference sound pressure (= 20μPa). It is worth noting that this relationship between the normalised impact sound level and sound reduction index is independent of the properties of the floor.

For octave frequency bands with centre frequency f_c, assuming FT infinitely short sinusoidal impulse and by substituting standard values for the ISO standard tapping machine [11], equation (4) takes the form:

$$L_n + R = 43 + 30\log f_c \quad (5)$$

Equation (5) is derived on the basis that the coincidence frequency is low and the surface is hard and has high input impedance. If the floor is soft or has a low impedance, the force produced on the floor is smaller and the time of contact with the floor is increased such that the assumption made to derive this equation may not be valid. Whilst this will cause equation (5) to give higher theoretical values than measured, this is not an inadequacy of the formulation proposed by Heckl and Rathe. With the correct force input, equation (4) still gives valid results.

However, in the case where the airborne sound travels along a different path to the impact sound, equation (4) is no longer valid. This case is associated with a hole in the floor or flanking transmission.

Using a power balance method, I. Vér derived the relationship between normalised impact sound level and sound reduction index [10]:

$$R + L_n = 43 + 30\log(f) + 10\log(\sigma_{rad}) \quad (6)$$

where σ_{rad} is the radiation efficiency of the impacted surface.

When a resilient covering is added to the bare floor L_n + R begins to deviate from equation (5) above a critical frequency f_1. This adaptation term is derived by H & L Cremer [12] and stated by Heckl and Rathe[9] as:

$$L_n + R = 38.6 + 30\log f_c - 10\log\left(1 + \frac{f_c^4}{f_1^4}\right) \quad (7)$$

f_1 can be found from the dynamic stiffness of the floor covering. For the purposes of this work f_1 is chosen empirically to best fit the data set.

It is from these equations that a technique to estimate the normalised impact sound pressure level of a floor is proposed.

It is proposed that the improvement to a normalised impact sound pressure level can be calculated directly from the ratio of the impulse response of the bare and covered floor.

This follow the work done by Ford et al. [13], where the improvement in level is given by the difference in force level:

$$\triangle L_n = L_{F,\text{bare}} - L_{F,\text{covered}} \quad (8)$$

where the force F =Ma(t), where a(t) is the acceleration of the hammer. As the mass of the hammer remains constant the improvement in normalised ISPL is given by:

$$\triangle L_n = 20\log\left(\frac{A_{bare}}{A_{covered}}\right) \quad (9)$$

where A = â is the acceleration spectrum. Using equation (5), the measured sound reduction index (R) and the change in level for bare and covered flooring given by equation (9), a method for making a normalised impact sound level measurement without the need for the usual impact level testing equipment is formulated. The normalised impact sound level of the covered floor is calculated by:

$$L_{n,covered} = [L_n + R]_{theory} - R - \triangle L_n \quad (10)$$

where $[L_n + R]_{theory}$ is the relationship given by equation (5). This is the equation which governs the impulse response method for rating impact sound insulation.

An Investigation of Covered Concrete Floors

Ford et al. [13] investigated the properties of impacting a covered concrete floor and the impact noise transmission characteristics of the floor. However, this investigation did not provide a method for evaluating a floor's impact sound insulation without making an impact sound pressure level measurement.

Ford et al.'s paper also shows an interesting aging effect for soft carpets. There is a considerable difference between the first and 5000th impact of the hammer on a soft carpet. As the hammer impacts the surface the carpet hardens causing the impedance to increase and increasing IPSL of the higher frequencies.

Calibration to a Reference Floor

In addition to the calibration checks required for the Uni-Tapper which are inherent in the ISO standard tapping machine as well and calibration checks of the accelerometer, it is proposed that impulse response methods procedure requires calibration to a reference floor.

In field tests on completed or partially completed floors, where a resilient floor covering is already present, it may not be possible to measure the impulse response spectrum of the bare floor. It is therefore proposed that impulse response methods procedure can be calibrated, given a reference floor that fits the conditions for equation (7), the impulse response method can

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be conducted calibrated to this floor given a known impulse response spectrum and f_1 for the reference floor.

EXPERIMENTAL SETUP & PROCEDURE

Testing was undertaken in the reverberation chambers at the Acoustics Testing Service, School of Architecture & Planning, University of Auckland.

The ISO tapping machine consists of five, 0.5kg weights suspended at 4cm, spaced equally over a span of 40cm. The weights are released at a repetition rate of 10 strikes per second (2Hz per hammer). The normalised impact sound level measurements are taken following the standards set by the ISO 140-7[11].

The Uni-tapper[14], shown in figure 1, consists of only a single hammer from the ISO standard tapping machine, and operates as a single hammer does in the complete machine, having a repetition rate of 2Hz. A type 4367 B&K accelerometer is glued to the hammer at the base of the stabilising shaft.

The testing procedure consists of accelerometer measurements made using the Uni-Tapper and normalised impact sound level verified with measurements made using the ISO standard tapping machine. The measurements are averaged from measurements made at minimum of 4 locations as required by the ISO 140 part 6 and 7[15, 11] standards.

The accelerometer measurements are also taken from the same locations and averaged in the same manner. However, as the ISO standard tapping machine consists of 5 hammers evenly distributed over 40cm, further study needs to be preformed as to the variations over this short distance. This effect should be negligible for non-periodic/homogeneous constructions but will become increasingly important for lightweight and periodic constructions.

Measurements are made at 10 locations spanning the area of the floor, 5 of which are oriented parallel/perpendicular to the boundaries of the floor and 5 oriented at 45° to the boundaries. From these 10 positions 210 unique groups of 4 positions are formed, calculated from the Binomial Coefficient expansion, equation (11).

$$C_r^N = \frac{N!}{r!(N-r)!} \tag{11}$$

where N is the total number of locations and r is the number of locations per grouping. This will give a spread of groupings which are well-correlated to the random location choices for the current testing procedure.

These 210 combinations of grouped positions are used to estimate the mean and error in the impulse response method, and standard method, for calculating a single value rating of $L_{n,w}$.

The inner workings of a simple accelerometer can be viewed as a damped mass on a spring. As the accelerometer is accelerated the mass is deflected from its equilibrium applying a force to a piezoelectric crystal, the larger the deflection the higher

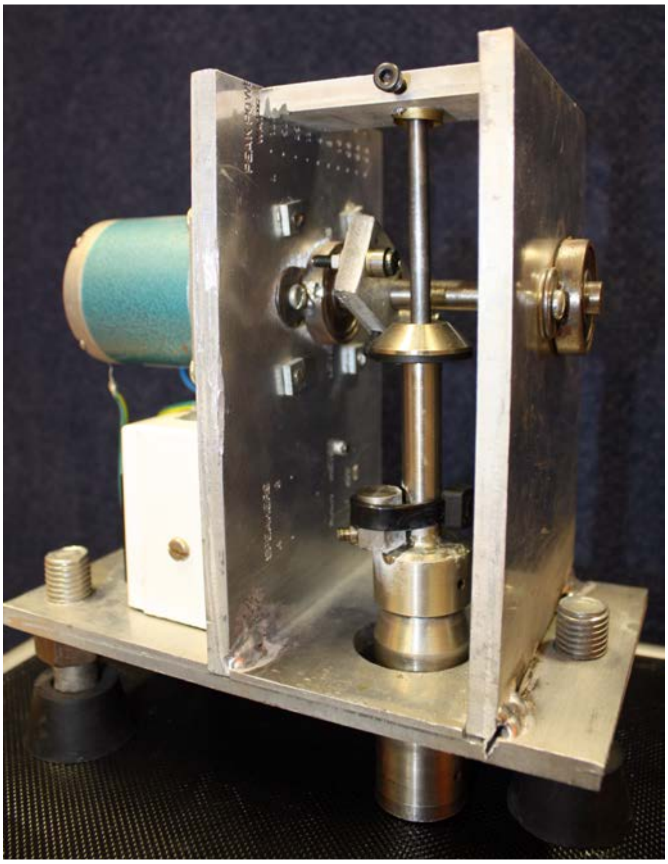

Figure 1. Uni-tapper with attached accelerometer.

the voltage output. There are different configurations to this simple accelerometer but almost all are based on this same principle[16].

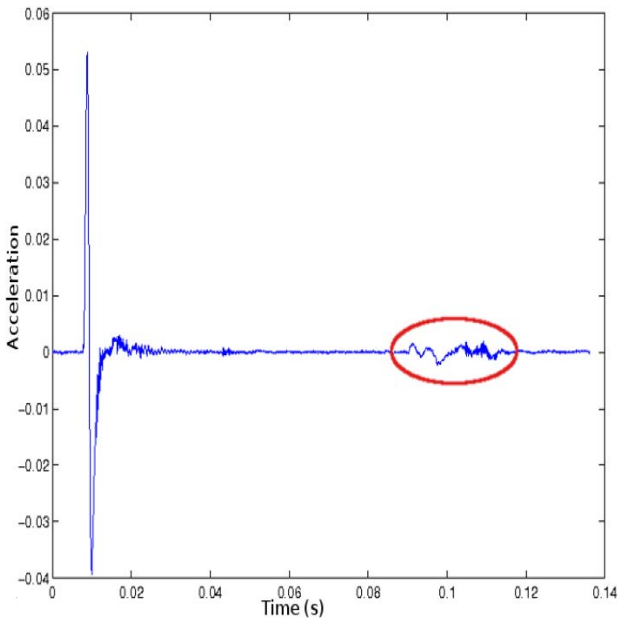

Figure 2.The low-pass filtered acceleration data as a function of time in seconds from the accelerometer on the Uni-Tapper hammer impacting on the ATC bare concrete floor. The acceleration associated with the hammer pickup is circled in red.

Figure 2 shows the acceleration of the pickup measurement and that there is a significant negative acceleration after the primary impulse. A negative acceleration would imply a downward force greater than the force produced by gravity, after the hammer has rebounded and started decelerating while airborne and thus not physical. This negative acceleration is therefore presumed to be due to the inner mechanics of the accelerometer. With such a large impulse the mass inside the accelerometer has enough momentum to be deflected back producing a negative acceleration.

RESULTS & DISCUSSION

VERIFICATION OF L_N +R RELATIONSHIP

Figure 3 shows the results measured using the ISO's standard tapping machine and the results derived from equation (10). The solid red lines show the relationships derived by Vér and Heckl & Rathe, equations (10) and (7), the hollow circles show the measured L_n+R. f_1 in equation (7) has been selected to fit the measured results.

This verifies the relationship shown by Heckl & Rathe in equation (7). f_1 has been chosen to fit the measured sum of L_n+R and is the first step in calibrating the impulse response method.

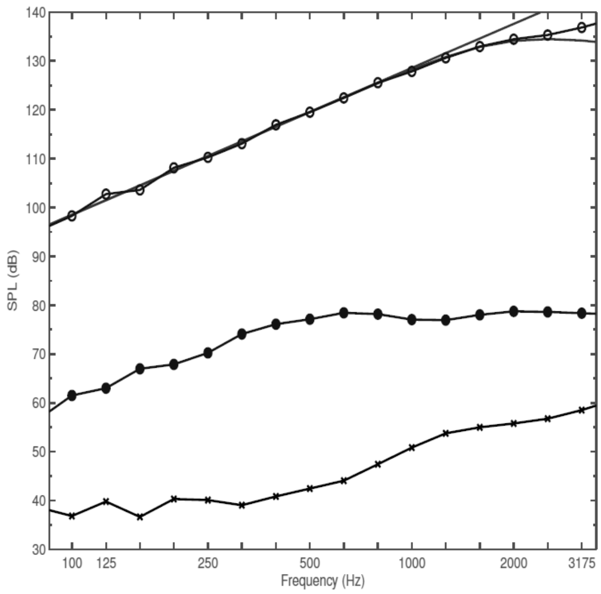

Figure 3. Verification of equation (7) to the measured L_n +R. Measured sound reduction index R (x) and Ln () and their sum L_n +R (o). Equation (10) is the straight red line and equation (7) is shown by the solid red line that begins to decrease to a -30dB/decade decline above 1900Hz.

IMPULSE RESPONSE METHOD

The data is low-pass filtered and as the normalised impact sound level is rated from 100-3150Hz; any data outside this frequency range is irrelevant. Applying a low-pass filter primarily reduces the noise for processing out the unwanted data from the pickup mechanism. The reduction in noise allows for an automated process to remove unwanted data.

Figures 4 and 5 show the normalised impact sound pressure levels (ISPL) on carpet and linoleum respectively. The normalised ISPL for the bare floor has been included in the following figures to emphasize the correction made by the difference in acceleration spectrum level. The normalised ISPL of a covered floor is calculated from the acceleration spectrum difference, between the bare and covered floor, subtracted from the normalised ISPL of the bare floor.

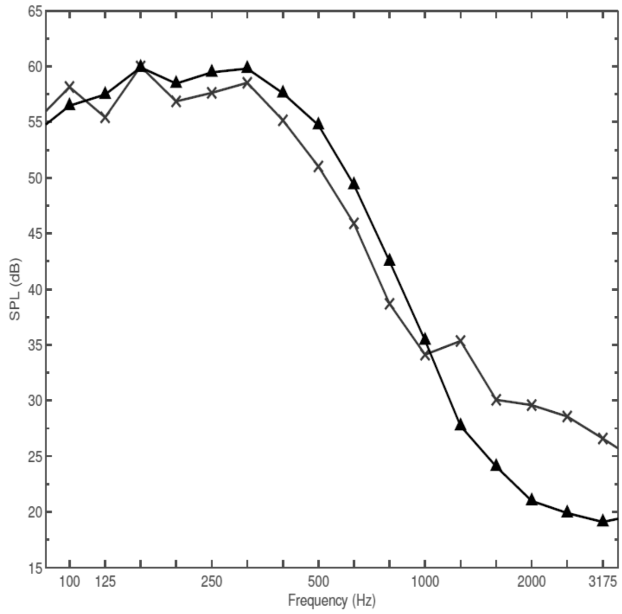

Figure 4. Normalised impact sound pressure level of the woodconcrete floor with a carpet floor covering, using only the acceleration spectrum of the hammer impacting the floor. Standard testing method(◆) and impulse response methods (x).

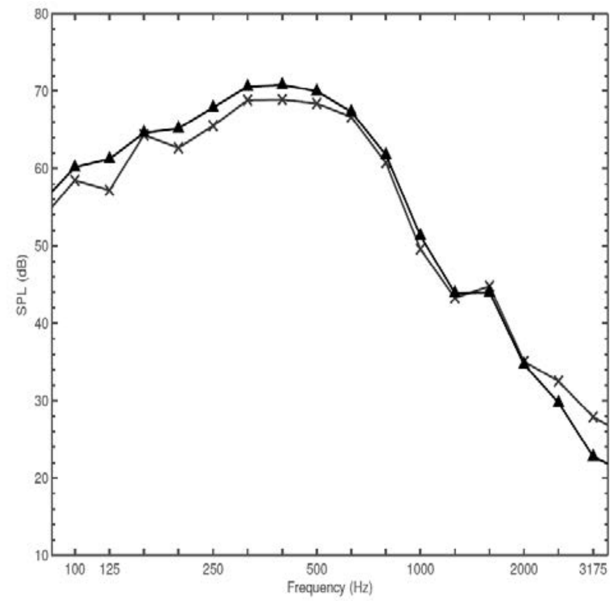

Figure 5. Normalised impact sound pressure level of the wood-concrete floor with a linoleum floor covering, using only the acceleration spectrum of the hammer impacting the floor. Standard testing method (◆) and impulse response methods (x).

This shows very good agreement between the impulse response method and standard method below the cutoff frequency where the acceleration spectrum of the covered floor becomes dominated by the acceleration of the pickup. This agreement can be improved at the higher frequencies by processing the raw data for the acceleration of the covered floors isolating the impact with floor, with any negative acceleration left in tact.

Due to flanking transmission inherent in floating floors the impulse response method does not at all agree with the standard testing method for lock-wood floor. There is an average difference in level between the standard testing method and impulse response method of 9.5dB.

The single value ratings of weighted normalised ISPL, $L_{n,w}$ shown in Table 1, show good agreement with the standard testing methods rating. It shows an approximately 1dB underestimation of $L_{n,w}$ by the impulse response method with the exception of the carpet covering.

The good agreement of the carpet covering is due to the poor agreement in the normalised ISPL in the high frequencies of the impulse response method compared to the standard method.

It needs to be noted that although the ratings of the bare floor and linoleum covering show an error estimation of ±0 does not mean there is no variation to the spectrum level.

The sum of the unfavourable difference between the measured L_n and reference curve can vary by as much as 10dB or more in a single shift of the reference curve, this means that a single value rating can be associated with a huge number of spectra with different curves. For example, the entire spectrum could shift by 1dB, and if anywhere up to 9 third octave bands are contributing to the unfavourable difference it is possible for the reference curve to not shift. It can therefore be very misleading looking at the accuracy of a single value rating.

Overall this shows very good agreement up to the cut-off frequency and shows very good promise as a method for rating floors ($L_{n,w}$) for screening purposes.

The poor agreement throughout the spectrum for the carpet covering will largely be due to a poor signal to noise ratio, as the signal is very low for the very soft floor covering.

Table 1. $L_{n,w}$, from 210 Combinations, of the Wood-Concrete Floor

	$L_{n,w}$ Impulse Response Method (dB)	$L_{n,w}$ Standard Method (dB)
Bare Floor	84 ± 0	84 ± 0
Cork Covering	63.2 ± 0.4	64.2 ± 0.4
Carpet Covering	52.9 ± 0.6	52.9 ± 0.3
Linoleum Covering	62 ± 0	63 ± 0
Wood-lock floating floor Covering	63.2 ± 0.7	70 ± 0

INFLUENCE OF BACKGROUND NOISE ON THE IMPULSE RESPONSE MEASUREMENT

It has been claimed that one of the largest advantages to the impulse response method is that it can be conducted even in places with significant background noise. Work done by A. Rabold et al. [17] showed that vibrations in the floor produced by the impacting hammer can have an effect on the subsequent impacts. This effect was primarily confined to low impedance floors at low frequencies but still raises the question that vibrations in the floor may effect the impulse response measured.

The effect of background noise on the impulse response measurements was investigated by subjecting the floor being tested to pink noise. The A-weighted overall level in the transmitting room is 107dB(A) and in the receiving room is 60dB(A).

Figures 6 and 7 show the mean acceleration spectrum levels with, and without, the background noise. Measurements were taken at 5 locations. It can be seen that even with background noise the difference in level, throughout the frequency range of interest, 100-3150Hz, is at most 3.2dB.

For the bare floor the difference in level between measurements with and without background noise shows a maximum difference of approximately +2.75dB and an average of 1.2dB.

For the cork covering the difference in level between measurements with and without background noise shows a maximum difference of approximately -3.2dB and an average of -1dB.

The aim of this work was to investigate a method of estimating the normalised sound pressure level, for the purpose of rating floors, that has several advantages over the standard testing method with the ISO standard tapping machine, this is the impulse response method.

The case where all the data pertaining to the impact, removing only the acceleration of the pickup catching the hammer and unwanted noise, shows very good agreement with the standard testing method.

One of the main advantages of the impulse response method is the ability to make impact noise measurements in noisy environments. This is a significant advantage in screening floors to ensure compliance to the building code during the construction process, where construction may be continuing within close proximity to the building element being tested.

Other advantages include reduced equipment size and weight. The size and weight of the tapping machine needed for the impulse response method are currently 1/3rd the weight and size of the ISO standard tapping machine. However, the entire testing method does require the measurement of the sound reduction index which increases the total equipment needed. In situations where a sound reduction index measurement were to already be made the total amount of equipment needed to make both measurements would be reduced. In this case the impulse response method provides a quicker and simpler testing procedure.

One of the disadvantages to this technique is the inability to make lateral impact noise measurements. Lateral impact noise transmission is not to the floor below but to rooms connected on the same level horizontally adjacent or below the floor being tested but adjacent to the room directly below.

The Uni-Tapper currently weighs approximately 3.6kg and is still relatively large in size (approximately 1/3rd the size of the ISO standard tapping machine), coupled with all the equipment currently used to conduct tests it is not an improvement to the difficulties and factors that make testing inconvenient. However, the weight of the Uni-Tapper could be reduced by using lighter metal for the framing and a lighter motor, reducing the weight further by approximately one half of the Uni-Tappers current weight. The equipment used to conduct the acceleration measurements could be replaced with a single amplification device exclusive designed to provide and impedance match between the accelerometer and the recording device. This would add negligible weight to the Uni-Tapper and fitted discretely within the electronics of the Uni-Tapper not effecting the size.

The recording device, in the current case a laptop, could also be replaced with small hand-held audio recording device, for field measurements, that would also server as the recording device for reverberation time and sound reduction index. It would also be possible to design a recording device, which once given all the necessary measurements of the sound reduction index, reverberation time and acceleration, could very quickly give a single value rating in the field. A more accurate representation of the normalised ISPL spectrum, could be found by further post-processing of the acceleration data after measurements have been made.

FUTURE WORK

Further tests on a wider variety of floor constructions and coverings need to be conducted to validate this technique for the general rating of floors. Variation of the impacting hammers head, for example rubber instead of steal, or by using a floor covering with a known change to the impulse response, could give a method of calculating the impact sound level of hard (and possibly more delicate) surfaces.

Further investigation of the impulse response method for rating floating floor configurations needs to be conducted. Although results have shown very poor correlation with the standard testing method it is possible a method of classifying the acceleration spectrum of a floating floor could be developed and rating system unique to the impulse response and floating floors could be employed.

With a reduced drop height and weight, a tapping machine which is considerably smaller and lighter could be manufactured. However, it has been shown using work by Lindblad [18] and a model by Brunskog [19] that nonlinear effects are likely to cause poor correlation with the standard testing method. This restricts changes to the hammer and to the drop height, however, it does not mean an expression for the improvement due to a floor covering could not be found. A standalone rating system could be formulated for the modified drop height, weight and even hammer design. It may be as simple as adding an adaptation term to this standalone rating

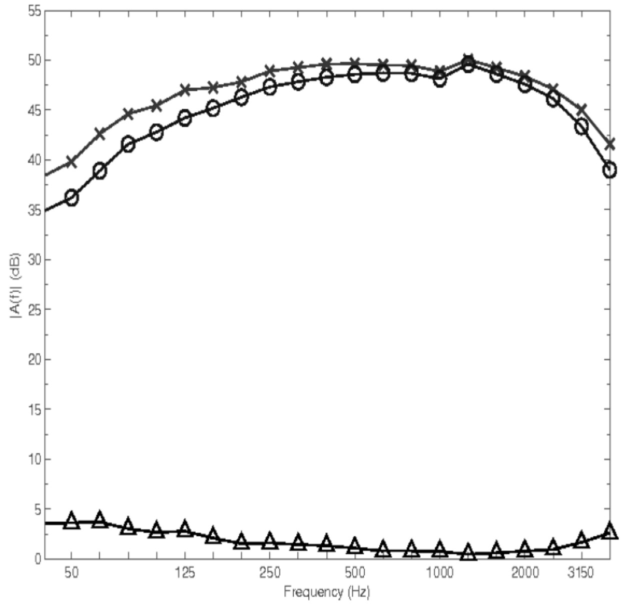

Figure 6: Acceleration spectrum levels of the bare floor with background noise.With (x), and without (o), background noise, and the difference (◆).

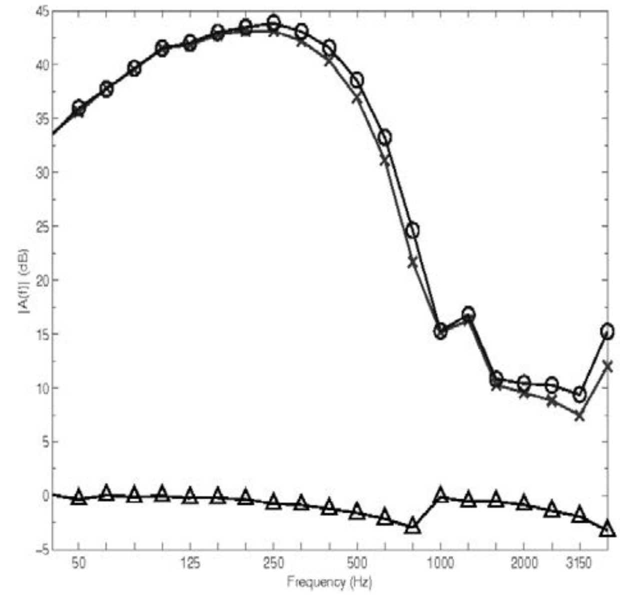

Figure 7: Acceleration spectrum levels with background noise, with a cork covering. With (x), and without (o), background noise, and the difference (◆).

to relate back to a weighted normalised IPSL rating or IIC rating. Further work would be required to investigate these possibilities.

CONCLUSION

All measurements of performance in building acoustics have a need for reliable results. Newly proposed ISO standards are discussed which outline procedures for establishing the uncertainties in such measurement results and new measures of performance to which these will need to be applied. Finally, a possibility for an alternative to the standard tapping machine for measuring the impact insulation between the levels in a multi-storey building is described. Whether or not this will be acceptable as a screening technique will depend not only on its successful practical development but also its ability to produce reliable results having low uncertainties.

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AUCKLAND UNITARY PLAN

The Auckland Council has released the first draft of its Unitary Plan and is inviting feedback. The Unitary Plan is the over-arching planning document that contains all noise rules for the Auckland Region.

http://unitaryplan.aucklandcouncil.govt.nz

The deadline for feedback is 31st May 2013, via their website link. ASNZ members are encouraged to read the draft and respond to council, to help ensure that its noise policies are well considered and robust.
