# Making and Using Building Insulation Measurements

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## ABSTRACT

Recently both Australia and New Zealand have felt the need to revise the noise control sections of their building codes. The focus for these codes is the protection of the quality of domestic environments in high density living conditions because of the increasing numbers of people choosing – or being forced into – city living. The success of these revisions depends on the appropriateness of the metrics used for the building insulation performance, the dependability of the way we make and use the measurements and any remaining uncertainties or omissions from the codes. The issues will be reviewed from a New Zealand perspective including –(i) the need for greater recognition of noise sensitivity, privacy sensitivity and social responsibility with respect to noisy behaviour and the use of loudspeakers, (ii) the relationship of measurements to the subjective assessment of building performance, and (iii) recent research on new techniques for conducting field measurements.

## 1. INTRODUCTION

The most recently available noise complaint statistics (see figure 1) and quality of life surveys in New Zealand indicate that – at least for residents in the major cities – we have not solved the problem of acoustic privacy (see section 2 for a definition) in housing.

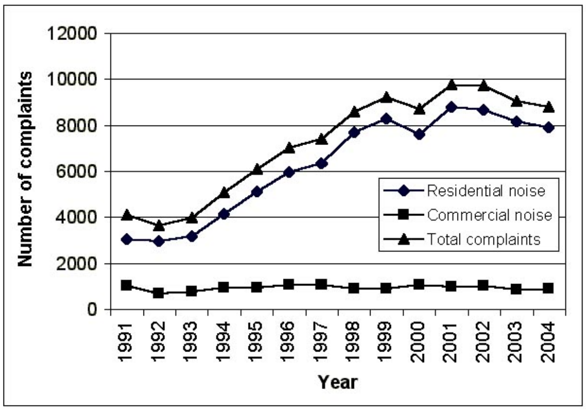

**Figure 1**. The noise complaints notified to Christchurch City Council since 1991 (Courtesy of T Moody, Christchurch City Council)

Building acousticians understandably tend to focus on the fabric of buildings and the associated insulation performance – as we shall in this presentation - but we must not forget that the human occupiers are responsible for the source of the problem sound. A major culprit is the way we use home entertainment systems (TV's, hi fi's and home cinema). It should be for the psychologists and sociologists to advise and encourage residents to be sensitive and responsible members of society but we acousticians are complicit in the provision and sanctioning of the high power, wide bandwidth equipment that cause the problem. Therefore we must warn of the dangers and implications of their use but, beyond that, our job is to try to meet the insulation needs for the level of activity and entertainment sound that society deems appropriate. Our aim is to provide conditions which neither constrain the freedoms of householders nor destroy amenity for neighbours.

This involves us in –

1. determining the needs and sensitivities of our population
2. measuring the noise and insulation in buildings, and
3. developing well-insulating constructions

In the next sections our work in these areas is briefly reviewed together with a more detailed presentation of some of our research on alternative measurement techniques.

## 2. INDIVIDUAL SENSITIVITIES

One result of a building code which specifies a single level of insulation performance (i.e. the minimum legally permitted [1]) is that it can unintentionally lend support to a view that everyone will be- or, worse, *should* be - content with the resulting acoustical conditions. When this is combined with legislation which uses/includes the term "reasonable noise" [2] we find there is a tendency to view residents who are chronically distressed by neighbour noise as "unreasonable" people.

We need to be more open about what percentage of the population is likely to be dissatisfied by buildings which just achieve code requirements. However that will only have real value if we have the means for reliably identifying those who *will* be dissatisfied.

We have suggested two psychological features that are likely to be involved –

1. Noise Sensitivity (NS) – which we define as *a person's tendency to be distracted by sound*, and
2. Privacy Rating (PR) – which quantifies a person's need for privacy and separation from others.

By means of experiments designed to measure a person's ability to push a variety of sounds into the background we have rated the NS of a group of test subjects. Then we used their responses to select questions which are effective as indicators of noise sensitivity and then combined these into a questionnaire tool for rating NS [3].

The development of a privacy-rating tool is ongoing work but our survey work so far has suggested the following as a definition for Acoustic Privacy – *the condition whereby no information about you or your neighbour (including your or their presence) is communicated by sound*. When we compared NS figures with self-assessed privacy ratings we found a similar figure of 14% for the percentage of the population with high NS and with a high PR (taken as more than 1 standard deviation from the mean).

In our subjective experiments we mow routinely screen subjects for NS and PR and we suggest that the use of NS and PR questionnaires could be of help in getting potential apartment, or town house, buyers to think about this aspect of their needs.

## 3. DEVELOPING AND RATING BETTER-PERFORMING BUILDINGS

Of considerable concern to the NZ and Australian timber industries has been the poor low frequency insulation performance of light timber frame buildings. This has prompted work to try to resolve the issue and we have been part of a group of researchers (sponsored by the Forest and Wood Products Development Council of Australia) undertaking a comprehensive study of timber-based floor-ceilings with the aim of producing designs which would provide insulation against impact sounds equivalent to that provided by a concrete slab floor-ceiling.

Some significant findings came from this work [4], [5] in addition to designs for solution floors (see figure 2). In order to demonstrate the relative acceptability of possible timber constructions and the concrete based floor we carried out subjective paired-comparisons of recordings of a range of impacts on the floors. These were reproduced with as complete visual and auditory fidelity as possible in a listening room satisfying the requirements of IEC Standard 268-13. The replay system had a bandwidth down to 12.5 Hz and presented the sounds from the ceiling.

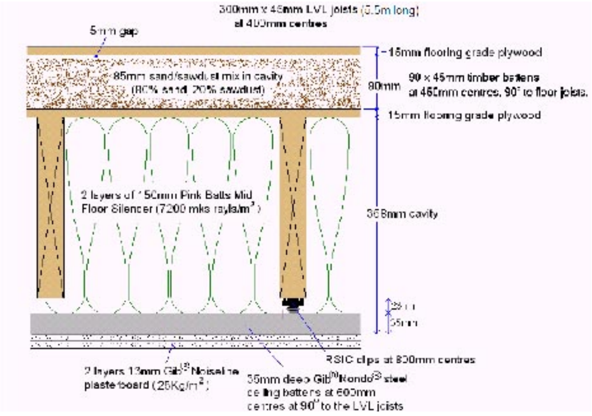

**Figure 2**: A design for an LTF floor-ceiling system which is subjectively equivalent to a 150mm concrete slab with suspended plasterboard ceiling for insulating against heavy impacts.

We found that the best predictors of the preference ranking of the floors were Loudness (in Sones, which we extended to include the infrasonic range) and A-weighted SPL (see Tables 1 and 2). By contrast, the ISO rating, Ln,w – even when including the impact spectrum adaptation term and extended down to 50 Hz – did not rank the floors well, as we might expect since the very low frequencies are excluded.

Especially significant is that the results showed that the preference ranking of the floors changed dramatically with the type of impact (e.g. the hard, light impacts of the tapping machine compared with the heavy impacts of the Japanese Standard Ball drop). This indicates that the performance requirements for building insulation (e.g. as specified in national building codes) cannot be satisfactorily stated in terms of a single number criterion.

**Table 1:** Subjective versus objective rankings of the floors assessed in the Listening Room when excited by the Japanese Standard Impact ball. Ref fl = 150mm concrete slab with suspended plasterboard ceiling underneath; fl2 – fl19 = various LTF floor designs (for details see reference 5).

| Ball drop | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ranking by Preference | Ranking by Subjective Difference | Ranking by Ln,w | Ranking by Ln,w + Ci | Ranking by Ln,w + Ci (50-2500) | Ranking by IIC | Ranking by LAeq | Ranking by Sones |
| Ref fl 1 | Ref fl 1 | fl 3 1 | fl 3 1 | fl 3 1 | fl 9 1 | fl 9 1 | Ref fl 1 |
| fl 9 2 | fl 9 2 | fl 9 2 | fl 9 1= | fl 8 1= | fl 3 2 | Ref fl 2 | fl 9 2 |
| fl 8 3 | fl 8 3 | fl 8 3 | fl 8 3 | fl 9 3 | fl 8 3 | fl 8 3 | fl 8 3 |
| fl 19 4 | fl 19 4 | fl 14 4 | fl 14 4 | Ref fl 4 | fl 14 4 | fl 20 4 | fl 20 4= |
| fl 18 5 | fl 20 5 | fl 18 5 | Ref fl 5 | fl 14 5 | fl 18 5 | fl 3 5 | fl 3 4= |
| fl 14 6 | fl 3 6 | fl 19 6 | fl 18 6 | fl 18 5= | fl 19 6 | fl 19 6 | fl 19 6 |
| fl 20 7= | fl 14 7 | fl 2 7 | fl 19 7 | fl 19 5= | fl 2 7 | fl 14 7 | fl 14 7 |
| fl 3 7= | fl 18 8 | Ref fl 8 | fl 2 8 | fl 20 8 | Ref fl 8 | fl 18 8 | fl 18 8 |
| fl 2 7= | fl 2 9 | fl 20 9 | fl 20 9 | fl 2 8= | fl 20 9 | fl 2 9 | fl 2 9 |

**Table 2:** Subjective versus objective rankings of the floors assessed in the Listening Room when excited by the ISO Tapping Machine. Ref fl = 150mm concrete slab with suspended plasterboard ceiling underneath; fl2 – fl19 = various LTF floor designs (for details see reference 5).

| Tapping machine | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ranking by Preference | Ranking by Subjective Difference | Ranking by Ln,w | Ranking by Ln,w + Ci | Ranking by Ln,w + Ci (50-2500) | Ranking by IIC | Ranking by LAeq | Ranking by Sones |
| fl 9 1= | fl 9 1 | fl 3 1 | fl 3 1 | fl 3 1 | fl 9 1 | fl 9 1 | fl 9 1 |
| fl 8 1= | fl 8 2 | fl 9 2 | fl 9 1= | fl 8 1= | fl 3 2 | fl 8 2 | fl 8 2 |
| fl 18 1= | fl 18 3 | fl 8 3 | fl 8 3 | fl 9 3 | fl 8 3 | fl 3 3 | fl 3 3 |
| fl 3 1= | fl 3 4 | fl 14 4 | fl 14 4 | Ref fl 4 | fl 14 4 | fl 14 4 | fl 14 4 |
| fl 19 1= | fl 14 5 | fl 18 5 | Ref fl 5 | fl 14 5 | fl 18 5 | fl 19 5 | fl 19 5 |
| fl 14 6 | fl 19 6 | fl 19 6 | fl 18 6 | fl 18 5= | fl 19 6 | fl 18 6 | fl 18 6 |
| fl 20 7 | fl 2 7 | fl 2 7 | fl 19 7 | fl 19 5= | fl 2 7 | fl 2 7 | fl 2 7 |
| fl 2 8 | fl 20 8 | Ref fl 8 | fl 2 8 | fl 20 8 | Ref fl 8 | fl 20 8 | fl 20 8 |
| Ref fl 9 | Ref fl 9 | fl 20 9 | fl 20 9 | fl 2 8= | fl 20 9 | Ref fl 9 | Ref fl 9 |

## 4. MEASUREMENT OF INSULATION PERFORMANCE

### 4.1 Relevance and accuracy

Since the aim of the objective measurement of insulation is to be able to label constructions according to their subjective value a decision is required as to the type – or types – of sound spectrum the constructions will be assessed against. The choice of a speech spectrum for the familiar STC and Rw ratings for airborne sound was arguably appropriate for the mid 20th Century but the minimal significance this accords to the lower mid-frequency range and the zero performance required at low frequencies (< 100 Hz)[2] make STC and Rw ludicrous assessments for today's conditions where the typical home includes audio equipment capable of considerable power below 100 Hz. The spectrum adaptation term, C, was adopted by ISO [6] to acknowledge the greater relevance of a music spectrum for modern living but this has not been accompanied by a formalisation of measurements below 100 Hz. There is informal advice in ISO 140 on making measurements down to 50 Hz but this can easily be taken by the uninitiated as suggesting (a) that anything below 100 Hz is not particularly relevant, and (b) that anything below 50 Hz is completely irrelevant.

The retention of a speech rating (i.e. Rw) as the basic ISO measure in ISO 717 and the C corrections as 'add-ons' has given support to a view that the spectrum adaptation terms are optional extras, but we must be brutally honest with ourselves (and with the professions we serve!) that Rw (and STC even more so) by itself is grossly inadequate for rating and specifying insulation for modern, high-density living conditions.

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[2] If a clever acoustical engineer were to design a barrier with zero TL below 100 Hz but which achieves STC 55 this would be legally acceptable currently in NZ!

Once an insulation value has been specified for a particular application the accuracy of prediction and measurement methods becomes an issue. Since all known codes express their requirements as numerical values attention becomes focussed on ensuring that methods can produce a result that is dependable within a certain value, - typically 1 dB. This means that the measured performance should be both repeatable within 1 dB and reproducible within 1 dB – as defined in ISO 140.

However, surely the more relevant issue is the accuracy of the subjective/perceived insulation. We expect that, all other things being equal, difference limen values for insulation will be around 4-5 dB (i.e. approximately the size of the quality and acoustic comfort categories used in some overseas standards [7], [8]). This suggests that by reporting the results of objective measurements to 1 dB (and making measurements made to 0.1 dB as is done to determine Rw) we are implying a level of significance for the values – and the performance of constructions differentiated by such amounts – beyond what is justified.

We need to institute a system of reporting insulation performance in a categorical way rather than a purely numerical way. This points to a need for more subjective research to establish how occupants react to sounds insulated to different degrees and filtered by different dependencies of R on frequency. The same applies to insulation against impact sound.

### 4.2 Needs for field measurements

Insulation measurements in completed buildings are needed for a various reasons –

1. to check that a novel system meets a building code
2. to diagnose a problem, or
3. as part of a quality assurance programme during construction.

But anecdotal evidence suggests that field testing is unpopular and viewed as challenging for reasons which include-

1. weight and volume of equipment required
2. on-site noise,
3. open-plan room geometries, and
4. tiny room volumes.

We have begun investigating ways for resolving these issues with the aim of increasing the popularity of field tests and to provide rapid but reliable ways of making screening measurements. Our first consideration has been the size and weight of the sources.

#### 4.2.1 Loudspeakers as sources

If we use a white or pink noise signal as recommended in ISO 140 we must take to the site a sufficiently large and powerful loudspeaker to achieve an adequate signal-to-noise ratio in the insulated/transmitted sound. The size and power of the loudspeaker may, however, be minimised if we replace the 'noise' by a deterministic signal (e.g. a maximum length sequence) and use coherent/synchronous averaging to build up the required signal-to-noise ratio. The use of such a method – based on extracting the impulse responses of the spaces - has other advantages:

a) the extracted impulse responses also provide the room RT's from which the room absorption can be obtained, and
b) when measurements are to be made in an already occupied building quite modest levels of signal can be used which are better tolerated by residents.

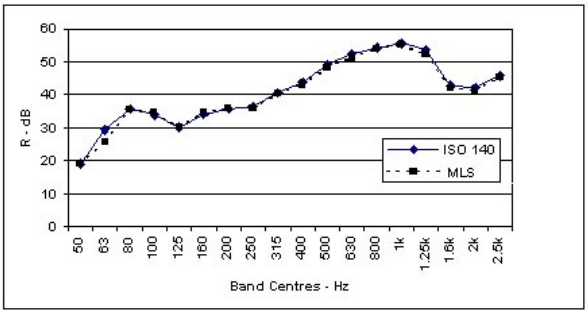

Figure 3: Comparison of the Sound Reduction indices of a wall measured with steady state noise (according to ISO 140) and with a Maximum Length Sequence signal (MLS)

Figure 3 shows the result of a measurement using this technique compared with the same structure measured by the standard method specified in ISO 140.

#### 4.2.2 Alternative airborne sound sources

An alternative to a steady loudspeaker sound is an impulse. The level difference between the energy in the impulse sound measured (simultaneously!) in the source and receiving rooms gives the same result as a steady-state level difference. The impulse sound decays also provide the RTs and hence we obtain all the information required for determining R or DnT.

Controlled explosions provide a good signal-to-noise and the most successful source we have tried so far has been the charges used for powder powered tools (e.g. Ramset and Hilti guns). For partitions which have only a modest insulation it is feasible to use the ubiquitous "Party Poppers" (available in every $2 shop) as an impulse source [9].

Since impact insulation measurements are likely to be required during a field check of a building the standard tapping machine will need to be on site and if used to provide airborne sound could make a loudspeaker unnecessary. Therefore we have experimented with using the standard tapping machine as a source of airborne sound by constructing a 'radiation box' for it to excite. Figure 4 shows a realisation of a simple rectangular radiation box where the top is made of a very high density fibreboard (Armour Board made by Fletcher Wood Panels) which provides a surface unaffected by repeated impacts from the hammers of the tapping machine. Because these impacts are repeatable and the radiation box remains constant the combination provides a reliable standard sound power source. This can be used for determining receiving room absorption from SPL measurements of the sound from the radiation box thus obviating RT measurements. Figure 5 illustrates how the SWL of the radiation box compares with the with that of the Bruel and Kjaer Reference Sound Power Source (type 4204), and figure 6 illustrates its accuracy as a sound power source by a comparison of the absorption of the ATS standard absorption sample obtained with the radiation box and by the ISO 354 reverberation method.

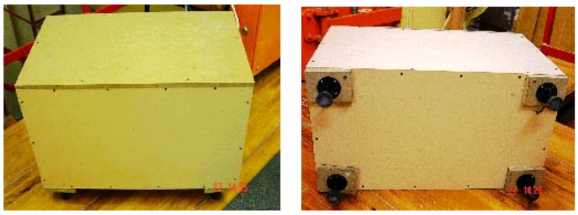
(a) (b)

**Figure 4**: Views of the 'radiation box' (a) top surface of Armour HDF, (b) the resilient mounting feet.

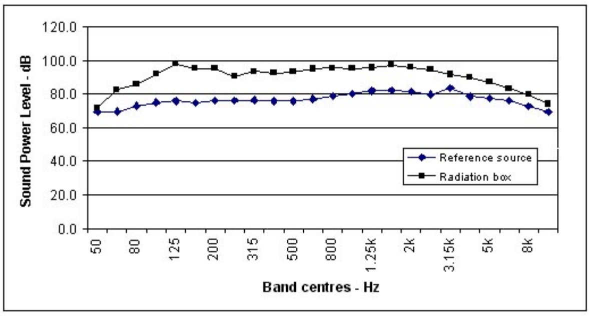

**Figure 5**: Sound Power Levels of the Radiation Box compared with the Bruel and Kjaer Reference Sound Power Source Type 4204

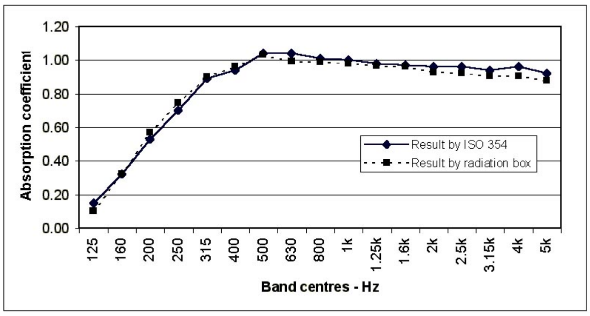

**Figure 6**: Absorption coefficients of a standard sample obtained by the reverberation method of ISO 354 and by the sound power method using the radiation box.

Finally, we've given consideration to the possibility of dispensing with a tapping machine completely and relying on a loudspeaker source (supplemented by a small impact hammer as necessary) for both airborne and impact insulation measurements. The tapping machine is not optimum as a source because –

1. it is heavy
2. it has fixed power, and
3. it's impacts are not sufficiently repeatable to permit synchronous averaging.

When there is a lot of site noise the tapping machine may have too limited power to provide a useable signal-to-noise ratio, and without synchronous averaging we are unable to complete a measurement.

We have begun to investigate the practicality of using the relationship between R and Ln first established in the early 1960's (see for example [10]) which shows that – apart from a correction for the frequency, f, of the band – the sum of the airborne and impact insulation for a hard floor is a constant i.e.

$R + L_n = 38.6 + 30\log f$ - for 1/3rd octave measurements.

Figure 7 illustrates this relationship for measurements made on the concrete floor separating chambers A and B in the ARC.

For floor surfaces which are not rigid or where there is significant flanking transmission via paths not involved in the transmission of the impact sound the relationship requires some modification. For the case where there is no significant flanking and we know the r.m.s. force, $F_T$, applied by the tapping machine in each band we have shown that the relationship becomes

$$R + L_n = 38.6 + 20\log f + 20\log F_T$$

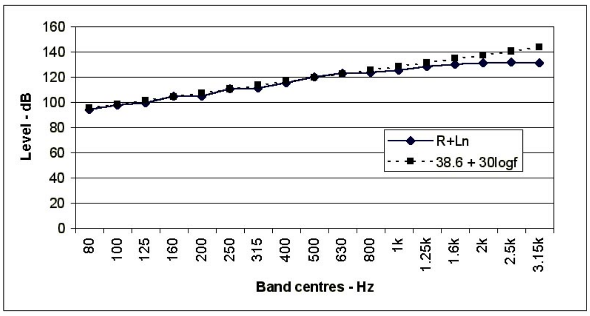

Figure 7: The sum of measured Sound Reduction Indices (R) and Impact Sound Pressure Levels (Ln) for a 150mm concrete slab compared with theoretical predictions for a hard floor. The departure from predicted values at high frequencies is due to the imperfectly hard surface of the floor.

Thus if we characterise the impedance of a floor surface by a manual impact hammer we should, knowing the characteristics of the tapping machine, be able to predict $F_T$, and hence extract Ln from a measurement of the airborne sound insulation.

Our current research also includes investigating the possibility of a reciprocal measurement technique for impact insulation where high noise levels confound a standard measurement. This involves using an airborne sound source in the receiving room with accelerometers to measure the floor response above. First we measure the average floor vibration levels produced by the tapping machine then find the vibration levels which airborne sound source levels in the receiving room produce. If the airborne source is a loudspeaker we can radiate a deterministic signal and use coherent averaging to get an adequate signal-to-noise ratio. Then by reciprocity we aim to extract the airborne levels that would be produced by the tapping machine.

## 5. Conclusion

In this paper we have summarised our view of the needs and problems that confront us if we are to improve the acoustic privacy for apartment and townhouse dwellers in NZ. Secondly, we have presented an overview of our work at the ARC towards encouraging more site testing of buildings by making insulation measurements easier and more convenient. This has involved investigations of novel sources to replace loudspeakers and possible alternatives to the use of a standard tapping machine for obtaining impact sound levels.

## References

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