Disclaimer

ACOUSTICS

IMPACT NOISE COMPARATIVES OF
FLOOR / CEILING SYSTEMS

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I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for examination to any other University or Institution.

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Silvana L. WiRepa

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Sincerely,

Silvana WiRepa

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ABSTRACT

On May 1, 2004, the Australian Building Codes Board (ABCB) introduced new sound requirements to the Building Code of Australia (BCA), part F5. The changes were a response to increasing evidence that previous requirements were not meeting community expectations.

In section FP5.1 of the BCA, it states clearly that:

“Floors separating –

(a) *sole-occupancy units*: or

(b) *a sole-occupancy unit* from a plant room, lift *shaft*, stairway*, public corridor*, public lobby, or the like, or a part of a different classification,

must provide insulation against the transmission of airborne and impact generated sound sufficient to prevent illness or loss of amenity to the occupants*”.* (source BCA[1])

The revised value was influenced by Acoustic Consultants’ experience with noise complaints, to reflect the lowest level at which it was felt that most people would not complain. Factors that added weight to the need for change was certainly the increase in complaints and litigation relating to noise between occupancies, and the disparity between the BCA and the higher standards imposed by many councils. Whilst the social benefits of the proposed level of acoustic comfort are impossible to quantify, the ABCB considers that the cost for a reasonable level of improvement are worth the expected benefits (CSR Gyprock – Concepts).

The change, it is believed, has brought about a reduction of 10 decibels (dB) by the introduction of the $L_{n,w}$ C_I 62 level of compliance which is a laboratory test for acoustic materials or systems to meet the criteria. But the question, still being asked by many acoustic professionals, is the level low enough to meet the increasing expectations of the end user (McCarthy, 2005) and does the perfect environment of the laboratory simulate the exact performance level of the same material or system in the actual field.

It seems that the construction industry is working against the acoustic profession by progressively reducing the quantity of concrete into structures. If the concrete slab

[1] Extract from the Building Code of Australia has been supplied with permission from the Australian Building Codes Board

density is increased, noise transference is decreased. The density of concrete mass reduces noise transmission it is believed, by 1 dB per 10mm in depth.

The prevailing level of thought of Australian Association of Acoustic Consultants (AAAC) is that the current BCA requirement is only a minimum standard and that the '62' compliance level is too easy to obtain (results are shown in chapter 5).

Although this study has been unable to record all the noises that can be heard in an apartment, it has simulated actual walking and the dropping of a 2.5kg sand ball on a number of different surfaces. A 2.5kg sand ball simulates heavy objects falling and the heavy thud of elevated running, furniture moving or boisterous children jumping.

Examples of real impact sound are:

- treading heavily or click clacking with high heels;
- hinged cupboards or sliding doors 'banging' on closure;
- 'dropping' items or jumping from height;
- 'dragging' a chair across the floor
- the 'vibration' of a washing machine on spin cycle (Nova).

This study will compare raw data generated on various surfaces, as well as judge the performance of materials and / or systems in the field to laboratory results. By understanding how materials and systems perform independently and comparatively is it possible to understand and / or anticipate how systems might perform.

Australia is in need of a comprehensive body of data so that information can be put to a computer formula in order to predict the performance of materials within a floor ceiling system. An actual site test should only confirm and certify the performance of a complete system for the relative authority and this information needs to be provided to the purchaser.

The ABCB needs to consider providing a compliance scale relative to a 6 star rating as offered by the AAAC. The AAAC rating is compared to McGowan's (2002) Typical Noise Limits, Bruel & Kjaer's PWI's Perception of Impact Noise in Dwellings and OSHA's Noise Thermometer in order to draw a recommendation (chapter 6). It is this recommendation that I believe would be of practical benefit to both the industry and end-users alike.

CHAPTER ONE

INTRODUCTION

1.0 RESEARCH AIM

The aim is to see how laboratory tested results of acoustic building materials and systems within controlled environments compare to newly completed apartments in the field. For consistency, tests will be conducted only within newly or nearly completed, untenanted and unfurnished units.

My objectives are to establish:

1. measurable differentials that may exist between laboratory tests and actual field tests;

2. assess the differences that various structural types may have on acoustic performance; and

3. compare the effectiveness of various acoustic materials and systems used in construction.

1.1 MEASURABLE OBJECTIVES

1. Test the acoustic performance of a floor / ceiling system referred to in this body of work as **type A system** within a newly completed or nearing completion apartment and compare against laboratory results of the same or similar system.

   Type A system - **250mm thick 40mPa concrete with 150mm air cavity and double layer 13mm plasterboard on a standard ceiling suspension system with shadowline corners. The structure has load bearing concrete block double and single walls with 250mm reinforced concrete slabs and a 4.5mm acoustic underlay under tile.**

2. Test the acoustic performance of a floor / ceiling system referred to in this body of work as **type B system** within a newly completed or nearing completion apartment and endeavour to compare against laboratory results of similar or same system.

Type B system – **270mm thick 40mPa concrete with no air cavity. Concrete slab sits on top of existing 22mm hardwood tongue and groove and 300mm x 45mm hardwood joists. The structure has discontinuous and single layer stud walls throughout.**

3. Test the acoustic performance of a floor / ceiling system referred to in this body of work as **type C system** in a newly completed or nearing completion apartment and endeavour to compare against laboratory results of similar or same system.

   Type C system – 220mm thick 40mPa concrete with no air cavity on top of existing 22mm hardwood tongue and groove and 300mm x 75mm hardwood joists. The structure has discontinuous and single layer stud walls throughout.

4. Test the acoustic performance of a floor / ceiling system referred to in this body of work as **type D system** in a newly completed or nearing completion apartment and endeavour to compare against laboratory results of similar or same system.

   Type D system – 180mm thick 40mpa post tensioned concrete with 150mm concrete load bearing concrete walls. The area that was tested had one layer of 13mm standard plasterboard with shadowline corners to the ceiling wall junction. No insulation in the ceiling with varied ceiling cavities of 150 & 350mm. The timber flooring system was an Acousta Batten (insulation between) with 19mm hardwood timber floor, and the bathroom areas had a porcelain tile on screed with waterproofing.

5. Compare the acoustic performance of Systems A, B, C & D.

1.2 HYPOTHESIS

1. The impact of dissimilar acoustic floor systems on acoustic performance levels.
2. The acoustic performance of acoustic floor systems compared to laboratory results of same or similar systems.
3. Ascertain to what extent the acoustic upgrade to BCA 2004 has been successful in determining improved acoustic standards in medium to multi-

density residential apartments as set out by the Australian Building Codes Board.

4. Whether the '$L_{n,w}$ + C_I 62' compliance rating, as specified by the Australian Building Codes Board, is an adequate acoustic performance criteria.

1.3 RESEARCH METHODOLOGY

In this study, the methodology will be to gather and absorb information and tests relative to 'impact noise' from relevant texts, laboratory manuals, Internet sites, building suppliers, Industry Associations and Australian Codes and Standards.

1.4 NATURE OF DATA – QUANTITATIVE

Once pertinent research information, data, literature and relevant material is gathered and understood, it will be necessary to identify the particular buildings to be tested. Once the buildings are chosen, then the building construction types are carefully noted along with the various materials used in the construction. This information is valuable when assessing the test results.

The field testing is purely quantitative.

1.5 COLLECTION METHOD

To measure impact noise it will be necessary to 'excite the floor' with a standardised impact source. The source chosen is known as a TAPPING MACHINE and produces a known force (mass x acceleration) at a known repetition rate in accordance with standard AS/NZS ISO 140.7:2006.

Sound levels are measured in the receiving room.

It is the receiving space (of the noise) that is tested. Modern apartments will be tested complete with hard surfaces devoid of furniture.

1.6 FORM OF ANALYSIS

Comparative.

1.7 AVAILABILITY AND RESTRAINTS

- Access to untenanted or unoccupied newly or nearly completed residential apartments.
- Reliant upon developers or builders being agreeable to access and testing.

- Restricting testing to buildings within a high density suburban environment.
- Identifying and classifying which buildings were specified under the new and old codes.
- The acoustic specialist being available when a building is accessible.
- Access to current data relative to the testing of modern building materials for comparison.

1.8 TIME CONSTRAINTS

- Building(s) being available in the time required.

1.9 LIMITATIONS

- Due to the sensitive nature of entering people's private homes, and then endeavouring to convince adjacent neighbours above and below, I have chosen to test newly or nearly completed apartments, devoid of furniture and occupants.

1.10 ASSUMPTIONS

- It is assumed that the quality of the building complies with 'good building' standards.
- It is assumed, that the latest engineering and finished drawings are in accordance with what has been actually built.
- That various materials are used in different ways with a range of construction types.

1.11 ETHICAL CONSIDERATIONS

- This study is not reliant upon an occupied apartment whereby a response of the occupant is required, but it is reliant upon the developer or builder providing or allowing access to conduct tests within their building for the duration required.
- It will be necessary to assure the developer or builder that the results will be confidential and will not impact adversely on the sale or public perception of their building. In order to respect their confidentiality, developers and builders will be assured that test results will be statistical and will not identify the building in the report.
- Assurance that the field tests will not damage floors, that the utmost care will be taken whilst conducting the tests.

- Written permission has been granted from Jackson Teese Architects to access information gathered by author Hunter Acoustics to quote from his research on Road Traffic Noise King St, Newcastle.
- Consent has been given by the CSIRO in Melbourne to include photographs of the laboratory.

CHAPTER TWO

REVIEW OF BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

Robert Caulfield of Archicentre within the RAIA, (building advisory service of the Royal Australian Institute of Architects) asserts "we are increasingly being asked to look at noise problems in apartments, units and flats. The main issue is that people have committed to purchase the property or have moved in before they carry out a noise assessment (RAIA, 2003). Caulfield has observed that with State Governments pushing to increase density in capital cities, the problem of coping with noise and other privacy issues will increase in the future. Archicentre is having to deal with advising people about the pitfalls associated with purchasing apartments off the plan or older residences by warning them that even their most intimate moments could become public if soundproofing in the building is not adequate. Caulfield commented that "many people who are spending thousands of dollars on apartments for waterfront views or special locations in inner city areas, could be in for a sound shock". (RAIA, Archicentre, 2003).

A recent case in Melbourne occurred whereby a group of residents in an apartment block petitioned the local council to take action against the alleged raucous lovemaking of one of the tenants. There was little to no soundproofing in the building at all (RAIA, Archicentre, 2003).

Renzo Tonin (Director of Renzo Tonin & Associates, member of the AAAC) stated in 2002 that "there has been a dramatic increase in the number of people living in high- rise apartments and townhouses and a corresponding venting of displeasure about the poor quality of sound insulation being provided in them" (Tonin, 2002). This comment by Tonin was prior to the BCA 2004 changes. At that time, some complaints could be traced to unacceptable building construction practices. The overall impression was that the minimum requirements in the BCA were not relevant to the current standard of living and it needed seriously upgrading (Tonin, 2002).

In today's architectural environment, good acoustical design is not just a luxury feature – it's a necessity. Acoustics impact on everything, including the market value of apartments, duplexes, townhouses and single-family dwellings. Each built environment offers its own unique set of acoustical parameters. Understanding these differences and knowing how to utilise building materials, system design and technologies are key factors behind successful acoustical design (Janning, n.d.).

With increasing concerns on environmental impact in Australia particular local authorities have recognised the intrinsic value of their cities by implementing policies to encourage people back into their central business districts (CBD) in order to revive these urban environments. They are achieving this by allowing more medium and multiple density development.

With an increasingly ageing population, ‘empty nesters’, career couples and a growing single population, statistics are showing that more and more Australians are moving towards a lifestyle with less encumbrances and low maintenance requirements to allow more free time and quality of life (Hay, 2001).

Real estate agents love to ’talk up’ city living. It’s all about penthouses, exclusive views, world-class arts precincts, a step away from this, a hop away from that. The buzz. The glamour. All on your doorstep (Fyfe, 2003).

Within the Greater Metropolitan Region (GMR) of Sydney, the Illawarra and the Lower Hunter (Newcastle), the Government policy of urban consolidation has resulted in the redevelopment and infilling of existing inner- and middle-ring suburbs predominantly in the form of multi-unit dwellings. But this intensification of urban areas through higher population and housing density has the potential to affect amenity (EPA NSW, 2003).

This research aims to investigate to what extent the new acoustic requirements in the Building Code of Australia 2004 (BCA, 2004) have addressed the issue of impact noise transference in medium to multiple density residential developments. It will compare laboratory results of floor/ceiling systems to the same system or product in a newly constructed apartment.

It will seek to identify the extent of the differentials + / - between laboratory tests of floor / ceiling systems and / or materials to field testing of the same system and / or material and whether they continue to meet the 2004 BCA requirements. It will seek to trace or understand the reasons for any differences and compare the industry accepted standard with techniques of actual live walking and by dropping a 2.5kg object onto the floor.

2.2 BACKGROUND - Building Code of Australia (BCA)

On May 1, 2004, the BCA introduced new sound insulation provisions as a response to increasing evidence that the previous BCA sound insulation requirements were no longer meeting community expectations (McCarthy, 2005). The purpose: to reduce sound transmission between attached dwellings and units and also between dwellings or units and other areas within the building. (The provisions do not address external noise).

The BCA is the uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia that applies to:

- all new buildings;
- new building work in existing buildings (additions & alterations); and
- existing buildings that undergo a 'change of use'.

Each state and territory has its own building control legislation that references the BCA as the technical standard that specifies the requirements for the design and construction of buildings. The building control authority within each state and territory (i.e. local council), determines the application of the BCA within its jurisdiction. This manner of application and administrative arrangements differs between states and territories due to recognition of local influences. At the time of writing, all but two states have adopted the code. Queensland and the Northern Territory have failed to embrace the new requirements.

In Section FP5.4 of the BCA2004, it states clearly that "Floors separating sole-occupancy units must provide insulation against the transmission of airborne and impact generated sound sufficient to prevent illness or loss of amenity to the occupants". Floor impact sound insulation ratings are classified under the deemed-to- satisfy provisions. The impact sound insulation requirements for floors are $L_{n,w} + C_I$ not more than 62 for floors separating dwellings. This formula is the Weighted Normalised Impact Sound Pressure Levels tested in the laboratory that results in a numerical rating. The lower the rating, the better the performance of the floor in terms of impact sound insulation.

According to Lafarge, a large building materials supplier in Australia, meticulous care goes into the installation of construction systems when testing in the laboratory but that actual site conditions are usually less than ideal and it is normal for sound flanking paths to exist around the perimeters which can have an effect on acoustic results (Lafarge 2005).

2.3 IMPLICATIONS

Good sound insulation is expensive. It is anticipated that the 2004 changes will add an extra 2% to construction costs of a building. Any extra thickness to walls, floors and ceilings means that 3% fewer dwellings can be fitted onto a development site. Costs then get passed down as developers require higher returns for each dwelling to maintain profit margins. It is estimated that nationally, the changes could cost the building industry an estimated $115 million a year (Nova, 2002).

2.4 CHANGING DEMOGRAPHICS – why the change.

The 20th century has been called the age of urbanisation. Early 19^{th} Century the world was predominately rural; only 8% of the population lived in urban settlements. By 1950, the percentage had risen to 29% and by 1990 to 45%. In the 21st Century, more people live in urban areas than in rural areas worldwide. In the last decade of the 20th Century, an increase of 83% of the global population occurred in towns and cities (HSC, CSU).

London has produced Canary Wharf, in Sydney Ultimo-Pyrmont and Green Square. Newcastle, albeit a large country town, is progressively reviving its city. It is in line with what is happening worldwide by rejuvenating an inner city suburb adjoining its inner harbour area known as Honeysuckle. This project is the local governments best cities program that continues to attract people back to inner city living. As the construction boom continues - people are continuing to migrate to city life (Farrelly, 2004).

Generous predictions have stated that 1,000 people a week will throng to Sydney (Goodsir, 2005). Australians are trading their traditional quarter-acre block in the suburbs for apartments, town houses and converted warehouses in central and inner city areas. We are now living and working physically closer to each other than ever before (Nova, 2002) as the quarter-acre block gets cut up into dual occupancy and low rise buildings give way to multiple density high rises.

Australia's inner city areas in major cities experienced high levels of growth.

TABLE 1 City Growth 2004-5 (ABS, 2004/5)

CITY	%
Perth	13
Melbourne	5.6
Adelaide	2.6
Sydney	1.6

2.5 GROWTH

Coastal Australia has experienced the largest growth outside capital cities. In NSW, increases in population includes Newcastle and Lake Macquarie. The statistical district of Newcastle recorded the second largest growth of the statistical districts (ABS, 2004-5).

2.6 LIFESTYLE

Demographics are changing rapidly. City lifestyles are becoming more attractive to a growing band of people who are leaving the suburbs for blue-chip multiple density properties particularly in Newcastle's central business district (CBD) (Croxton 2004). The popularity of ocean and harbour-front apartments are drawing more people to the city.

When these new apartments feature expansive city, ocean or river views and large floor areas, sizeable balconies, individually controlled air conditioning, undercover security parking, storage, lap pools, gymnasium, health spas, commercial shops, key card security, concierges and the like, this lifestyle is regarded by many as being more attractive than the quarter acre block with its labour intensive maintenance requirements (Bentley 1999).

When one bedroom apartments have starting prices of $200,000 (The Plaza) (Keene 2004) in the CBD of Newcastle (equivalent to a 3 bedroom house in some suburbs) to more than $2.6 million for a penthouse, of course high expectation of that unit's performance is demanded.

The people moving into the CBD of Newcastle (as in other major cities) are, according to Leone Hay, "a mix of young and middle-aged couples, as well as retirees wanting an alternative to a retirement village" (Hay, 2001).

Developer Scott McKenzie, of McKenzie Holdings, says "People have identified that apartment living is a good way to live". This sentiment is echoed by a couple, both in their early 60s, who sold their Coal Point home (a respectable lake-side home in Newcastle) to purchase a three-bedroom sub-penthouse because they wanted a lifestyle change. They chose to convert to apartment living because of the proximity to restaurants, theatres, the urban environment and low maintenance (Hay, 2001). It's all about lifestyle.

According to Newcastle's mayor, Councillor John Tate, 'there is only a finite number of these development sites' (Hay, 2001). Aware that Newcastle has a small CBD footprint compared to other cities, such as Sydney for example, Newcastle is bordered by waterfront and with the limitations of height set by the Cathedral on 'the Hill', Counsellor Tate continued to say 'I believe there won't be enough apartments for the demand' (Hay, 2001).

Alan Taylor, development manager for Stronach's (construction company) stated 'There's a lot of empty nesters out there, and that implies couples, but there's also a lot more single people' (Croxton, 2003).

All fine and well, but when you mix early retiring 'empty-nesters', with 24-hour single party people who are increasingly living 'cheek-by-jowl', and where there is considerable investment in 'surround sound' home cinema systems, with trendy floorboards to dance away the night upon, you get the sense of the potential for 'unit rage' (Fletcher, Soundblock, n.d.).

2.7 AMENITY (and quality of life)

Greater consideration to amenity is growing as our population and housing densities continue to increase in our cities. 'Amenity' relates to the qualities, characteristics and attributes people value about a place which contribute to their experience of 'quality of life'. People desire a life free of nuisances that may arise from sources such as vibration or noise through impact transference and this is why correct acoustic assessment and implementation is so important.

2.8 URBAN INTENSIFICATION

As urban population and housing densities grow, amenity values can come under potential threat (EPA-NSW, 2003). Most people living in urban environments have experienced one or more changes to their amenity as a result of urban intensification. As the value of property increases, so too does consumer and end-user expectation. However, there is increasing recognition of the importance of amenity and its management within Australia and abroad. Studies in New Zealand have identified a range of potential urban amenity indicators that include noise and vibration (EPA, 2003). Data for impact noise transference gathered by testing the performance of acoustic materials or systems are difficult to obtain as many of the results are retained due to 'commercial-in-confidence'. Suppliers are wary of revealing comprehensive and comparative results in order to maintain an edge within competitive markets and provide information on a 'need to know' basis. Data, if compiled, could provide indicators and baseline data as a basis to current building codes, that could contribute towards establishing acceptable benchmarks or indicators and/or levels over time (EPA, 2003).

2.9 GENERAL NOISE & ENFORCEMENT AUTHORITIES

Some councils have addressed noise issues within their Land Environment Protection (LEP) and have Development Control Plans (DCPs) that provide acceptable noise criteria for development where problems are more likely; these can exceed the range of potential urban amenity indicators that include noise and vibration (EPA, 2003).

In 1996, the City of Sydney took matters into its own hands and upgraded the sound insulation performance for buildings in its jurisdiction. The Association of Australian Acoustical Consultants (AAAC) also wrote to the ABCB pleading for changes to the BCA. The ABCB recognised that councils going their own way would result in a proliferation of sound insulation standards having the effects of undermining the intent of the BCA and (potentially) complicating regulation (Tonin, 2002).

The Protection of the Environment Operations Act (PEOA) and the Protection of the Environment Operations (Noise Control) Regulation 2000 provides the legal framework and basis for managing unacceptable noise in NSW. The PEO Act identifies responsibility for regulating noise and empowers the EPA, Waterways Authority, local government and NSW Police to use a range of regulatory tools to address noise. These include noise control notices, prevention notices, and noise abatement directions and orders. In NSW no single government authority has overall responsibility or capacity to control, reduce or manage all forms of noise pollution (EPA 2003).

Table 2 shows some of the enforcement authorities responsible for various types of noise in NSW (note that impact noise generated within a building is not regarded because it is a situation that has to be addressed prior to planning by the local planning authority) (EPA 2003).

Local councils, the EPA, and the Police all receive complaints about noise. Local councils are thought to receive the most but statistics on the total number of noise complaints received by council is not readily available owing to the fact that noise varies considerably (EPA 2003) and the response to ‘impact noise internally generated’ is virtually impossible to track. (Note: impact noise is not identified).

2.10 TYPES OF COMMUNITY NOISE

TABLE 2 TYPES OF NOISE (EPA NSW, 2003)

Types of Noise	Enforcement Authority
Aircraft	Air Services Australia
Barking Dogs (and other domestic animals)	Council
Road Traffic	Roads and Traffic Authority

Car sound systems	Council, EPA, Police
Car and house alarms	Council, Police
Noisy neighbours	Council, Police
Garbage collections	Council
Lawn mowers	Council
Building and construction	Council
Household appliances	Council
Mechanical devices (swimming pool & spa pumps)	Council
Regulated devices (power tools and lawn mowers)	Council
Air conditioning and refrigeration equipment	Council & EPA
Noise from clubs / pubs	Liquor Admin Board
Trains	EPA
Industrial noise	Council, EPA
Vessels (power boats, jet skis)	Waterways Authority

The EPA Pollution Line received 1255 noise complaints in 2002–03, accounting for 12% of all incident calls about activities regulated by the authority (see figure below). According to the EPA this was an increase of over 15% on the year before when only 1088 calls related to noise were received.

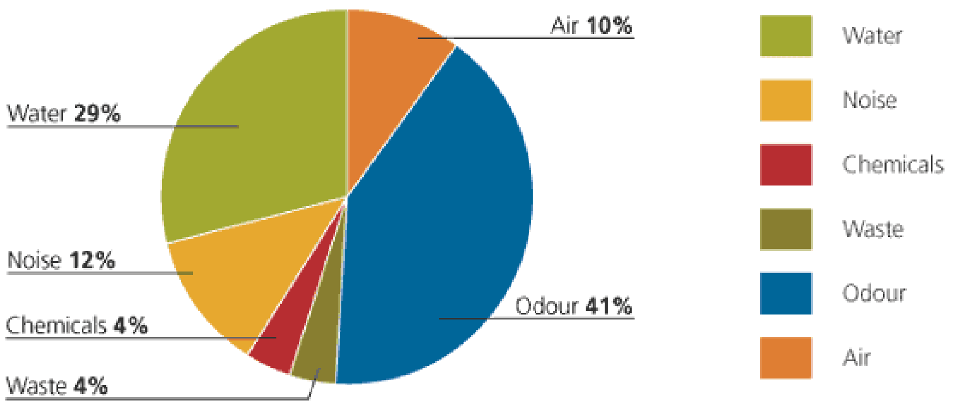


FIGURE 1 - EPA Pollution line incident calls, 2002 –03 (Source EPA , July 2003).

(The data does not include 5,819 requests for information about noise issues to the Pollution Line (14.5% of all information calls received)).

The power to enforce controls regarding residential noise has been delegated under the Act to local government and the police, while individual persons affected can take action under the legislation (McGowan, 2004).

Table 3 highlights the noise levels we should expect in various areas (residential, commercial, industrial) during different times of the day, evening and night times. It indicates typical noise levels that we should expect.

TABLE 3

TYPICAL NOISE LIMITS (AT SENSITIVE RECEIVERS) (McGowan, 2004)

	Typical Noise Limit dBA		
Description of Area	**Day* 0700-1800 hours**	**Evening 1800-2200 hours**	**Night 2200-0700 hours**
Mainly residential area	**50-54**	**44-48**	**39-43**
Area with some commerce or industry	54-59	48-52	43-47
Commercial district or bordering an industrial area	59-63	52-57	47-52
Predominantly industrial area	63-68	57-61	52-56

***On Sundays and public holidays between 0700 and 1800 hours the evening noise limit applies.**

We need to contain and reduce noise in order to enjoy a healthy life and reduce our impact on others, particularly in high density areas (Greenhouse).

Little can be done if impact noise is an issue post-occupancy when the construction has complied with the code at time of approval.

2.11 THE SCIENCE OF SOUND

Technically speaking, sound is defined as a vibration in an elastic medium. An elastic medium is any material (air, water, steel) that has the ability to return to its normal state after being deflected by an outside force such as a sound vibration. The more elastic the substance, the better it is able to conduct sound waves (Janning, n.d.).

2.12 HISTORY

In Germany 1932, a person by the name of Reiher developed the evaluating method of floor impact noise using a tapping machine. In 1953, Germany standardised the method for measuring floor impact noise for the laboratory and in-situ experimentation (DIN-52211) and for the first time established a structure construction guide (DIN 4109) for floated floors. From these results, various countries have established their own measuring methods post-1950 (Jeon et al, 2002).

In 1965, Watters reported the experimental results about the characteristics of floor impact noise in terms of the floor impact spectrum of the tapping machine and women's high healed shoes. However, Olynyk and Northwood reported that the noise evaluation using a tapping machine is difficult to replicate the real impact characteristics of a floor (Jeon et al, 2002)..

2.13 ROOM ACOUSTICS

When noise strikes a wall it can be reflected, transmitted, absorbed or diffracted.

- Reflection or reverberation (noise bouncing)
- Transmission (passing through barrier)
- Absorption (wall or floor absorbing noise)
- Diffraction (noise leaking through around or under small spaces)

  (Foundation Science, n.d.).

Our personal perception of noise is affected by subjective factors. These include: the type of noise, our mood, time of day, background noise levels and our expectations.

People react to noise in different ways. We take most sounds for granted, but when the 'sound' becomes a 'noise' it is distracting, breaking concentration. When this happens, it is identified as unwanted. What is a sound to one person could be another person's ticket to insanity (Fyfe, 2003). It is very subjective.

Often it is not the pitch or the loudness that makes the noise annoying. According to Richard Dowell, a professor of audiology and speech science at the University of Melbourne and The Royal Victorian Eye and Ear Hospital, says 'the most annoying sounds are the ones that you have little control over' (Fyfe, 2003).

British noise pollution research suggests we get annoyed more easily because we are less neighbourly – having less social contact reduces our tolerance of neighbourhood noises. We are now decorating more sparsely, with a fondness of floorboards and tiles, indeed anything except carpets and heavy drapes that help block sound (Fyfe, 2003). To reiterate, the trend, as we are experiencing it, is that our cities are being built up rather than out. Also, because executive apartments are becoming more costly, our expectations are higher.

2.14 HEALTH ISSUES

Although we recognise noise pollution as a major environmental problem, it is difficult to quantify the effects it has on human health. Exposure to excessive noise has been shown to cause hearing problems, stress, poor concentration, productivity losses in the workplace, communication difficulties, fatigue from lack of sleep, and a loss of psychological well-being (Nova, 2002).

While work-related hearing loss is on the decline, Professor Dowell says 'problems such as tinnitus – where a noise heard in your head or ears is not really there and is usually associated with some damage to the ear – is now suffered by up to 20 per cent of the population" (Fyfe 2003).

2.14.1 Hearing

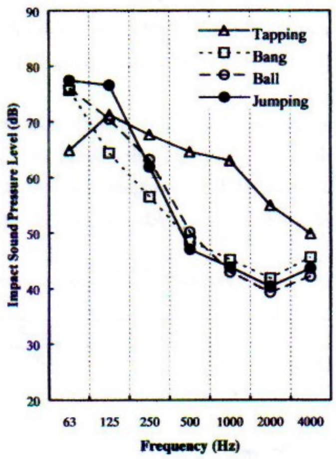
The human ear can receive a wide range in terms of loudness, from the very faintest rustle of leaves to the sound of a jet plane taking off. Above 120 dB sound becomes very painful and lower levels such as 85 dB can actually damage the inner ear if exposure is long and frequent (Foundation Science, n.d.).

2.14.2 Floor Impact Noise from Different Impact Devices

Part of the series of tests conducted by Jeon et al, was to compare the tapping machine (ISO 140-7:1998), with the bang method (tire, JIS A 1418-2) and ball drop (JIS A 1418-2:2000) methods to the jumping of an adult in their 20's of weight between 65-70 kg. They recorded jumping noise as the most frequently produced sound during an adult walking and a child playing in a multi-story residential building (Jeon et al, 2002).

Figure 2 demonstrates that jumping in the maximum sound pressure level is similar to that of the bang machine and the ball. The rubber ball drop is particularly closer to the noise generated from actual live jumping.

FIGURE 2 - FLOOR IMPACT NOISE FROM DIFFERENT IMPACT DEVICES



Floor impact noise from different impact devices.

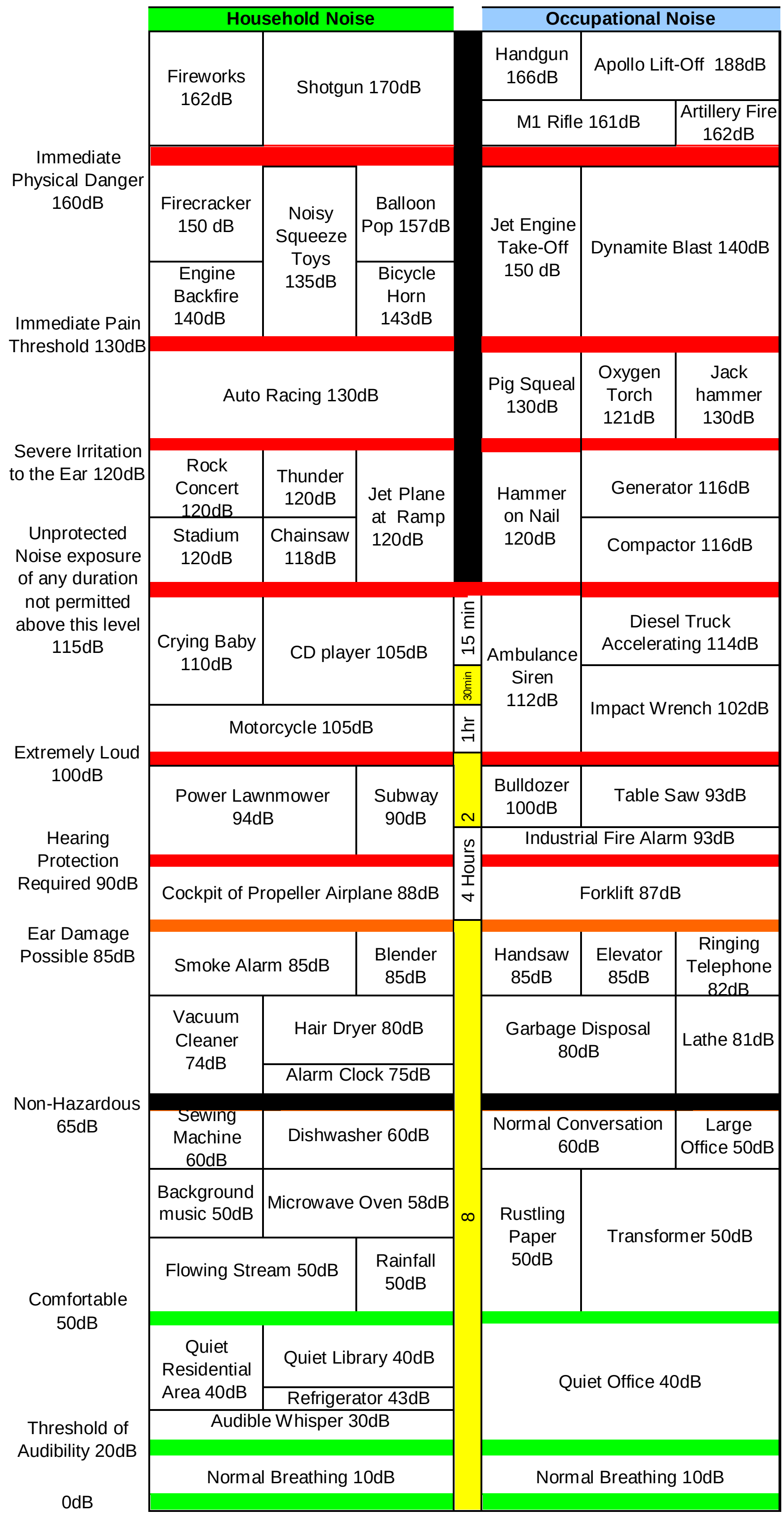
Source Jeon et al. (2002)

TABLE 4 OSHA Noise Thermometer

(Occupational Safety & Health Administration, USA)

Noise Thermometer

According to OSHA, noise doubles every 3dB.



According to OSHA, Occupational Safety & Health Administration, USA, (the equivalent of Australia's Occupational Health & Safety Organisation), their noise thermometer indicates the threshold of audibility at 20dB a whisper at 30dB, 40dB is a quiet residential, library or office area, and a comfortable noise level is 50dB.

The Building Code of Australia's '62' rating is almost the equivalent of the sound that a sewing machine makes, a normal conversation or the rumble of a dishwasher. OSHA also regards 65dB as being non-hazardous and the table indicates that the human ear can sustain noise levels up to 85dB for a duration of 8 hours.

A vacuum cleaner emits 74dB, an alarm clock 75dB, a ringing telephone 82dB, but an ear piercing smoke alarm, particularly at close range, rings out an 85dB. It would be safe to assume that these numbers are averages. An extension of this study would be a comprehensive look into people's tolerances, for example, various levels of noise output up to 85dB in a range of moods, time of day and personal ages.

TABLE 5 Perception of impact noise in dwellings as a function of impact sound insulation L'_{nTw} (adapted from PWI: Schaololschutz im Hochlau, Maienfeld, 1997,

L'_{nTw} (dB)	Noise generated in adjoining room			
	Normal Walking with normal footwear or house footwear	Elevated running children or walking barefoot	Extreme moving furniture and boisterous children	
	Perception of resulting noise			
63	Audible - intrusive	Very intrusive	Unbearable	Unhappy
58	Audible	Intrusive	Very intrusive	
53	Barely audible	Audible	Intrusive	Neutral
48	Inaudible	Barely audible	Intrusive	Happy
43	Inaudible	Inaudible	audible	

Bruel & Kjaer

Source: Bruel & Kjaer

According to Bruel & Kjaer, "In many countries, present building regulations operate with a limit of around 53 dB".

The chart by Bruel & Kjaer (Table 5) identifies 63 dB as audible and intrusive when persons are walking normally with normal footwear within the source area. It shows the tolerance level decreasing when children are running or walking barefoot when the perception of the resulting noise becomes very intrusive. When the noise generated from the adjoining room is from boisterous children or furniture moving, the response is recorded as unbearable.

Decibel readings between 58 and 63 records the recipient response as unhappy, 53 dB as neutral and between 43 to 48 dB as happy. When occupants in the source room are walking normally with normal or house footwear, the chart indicates the noise level as being virtually inaudible.

2.15 SOUND

Sound is described according to its highness or lowness. This is its frequency or pitch and is measured in Hertz (Hz). Sound is also described according to the loudness or softness. This is its loudness or intensity measured in decibels (dB) (Foundation Science, n.d.). Humans can typically hear sounds in the range 20Hz to 20kHz depending on factors such as age and gender.

2.16 FLOORS

This study will review the workability and effectiveness of the current Building Code of Australia requirements in addressing the reduction of noise impact through floors. It will address the said topic limited to and within medium to multi density class 2 residential buildings. It will discuss noise transmitted by impact from one space to another within a building. It will compare laboratory results of the acoustic systems and/or materials against site field tests of the same systems or material.

When considering impact noise in relation to residential development, (also known as structure-borne sound transmission), it is the transfer of vibration through sound waves audible in a receiving space. Examples of impact sound are as follows:

- treading heavily or with click clacking high heels;
- hinged cupboards or sliding doors ‘banging’ on closure;
- ‘dropping’ items or jumping from height;
- ‘dragging’ a chair across the floor
- the ‘vibration’ of a washing machine on spin cycle. (Nova)

This study will seek to compare tests of various building materials and systems within controlled environments against their performance within newly completed apartments in the field.

Tests will be conducted within newly completed, untenanted and unfurnished units. It is anticipated that I may be able to establish:

1. measurable differentials between laboratory tests to actual field tests;

2. assess the differences that various structural differences may have on acoustic performance;

3. effectiveness of various acoustic materials and systems used in construction.

The 2004 Building Code of Australia provisions have made amendments to the way floors between dwellings are assessed. The new provisions include an impact noise level rating and have incorporated a sound spectrum adaptation rating for airborne sound transmission. In addition, the new provisions apply to all floors within dwellings and not just habitable rooms (BCA 1996). Lastly, all hard surfaced floors require a resilient underlay and/or a resilient mount ceiling system to the dwelling below floor level (McCarthy, 2005).

The introduction of impact rating $L_{n,w}+C_I$, ($L_{n,w}$ - weighted normalised impact noise level and C_I - spectrum adaptation term), has been established to combat impact noise, both resonating through the building structure and impact noise becoming airborne sound invading the privacy of the separating dwelling below. $L_{n,w}$ (weighted normalised impact noise level) is a standardised method of measurement. It assesses the difference in noise levels from one space to another. C_I (spectrum adaptation term) is the frequency spectrum adaptation term used to measure and combat noise such as footfall (McCarthy, 2005).

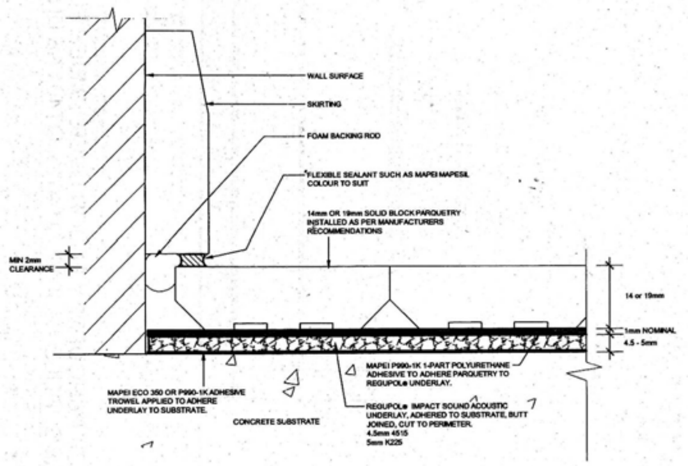
TABLE 6 - COMPARISON OF FLOORS – Building Code of Australia

	BCA 2004		**BCA 1996**	
ITEM	Sound Transmission	Impact Requirement	Sound Transmission	Impact Requirement
Inter-tenancy	$R_w + C_{tr}$ 50 or $D_{nt,w} + C_{tr}$ 45	**$L_{n,w} + C_I$ 62**	R_w 45	-

2.17 RESILIENT UNDERLAYS or CEILING SYSTEMS (Regupol®, Rondo Resilient Mount, Acousta Batten)

The following diagrams illustrate the various acoustic materials and systems available and on the Australian market that includes, Regupol, Resilient Mount ceiling systems supplied by Rondo and Acousta Floor Battens. It is these acoustic systems that have been field tested.

REGUPOL



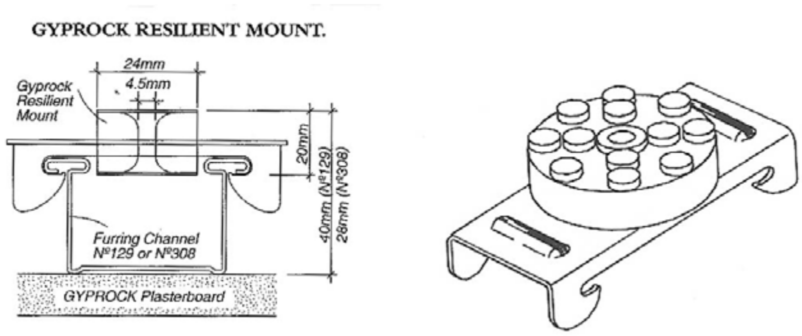
Source – Regupol ®

FIGURE 3 – DIRECT STICK PARQUETRY FLOOR WITH ACOUSTIC UNDERLAY - REGUPOL

Regupol ® puts out a range of products that can be laid under tiles, timber floors, screeds, carpets and vinyls. It is manufactured from recycled rubber fibres and blended with polyurethane binders. It is best known for its attenuation of impact sound and vibration under various floor coverings and mechanical loads. Materials can be supplied in rolls, sheets, tiles and strip form. Thicknesses vary from as little as 3mm to a dimpled mat of 17mm at its thickest.

Regupol ensure they have fully trained installers to ensure the product is laid in accordance with the specifications for installation.

RONDO RESILIENT MOUNT



Source – CSR Red Book

FIGURE 4 – SOUND ISOLATION RESILIENT MOUNT SYSTEM

Wall and ceiling sound isolation assembly for Rondo furring channel.

The resilient mount system has been designed to improve the acoustic performance in suspended screw fix ceilings. The pin through the centre of the unit has connection with the rubber only i.e. the system is designed so that the rubber absorbs vibration through the unit. The product supplier recommends that the resilient mount system be used with at least two layers of plasterboard and insulation within the ceiling cavity.

ACOUSTA BATTEN

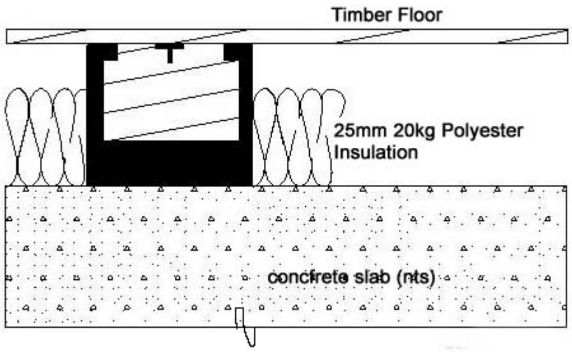


FIGURE 5 – ACOUSTA BATTEN

DESCRIPTION of Acousta Batten

$L'_{n,w}$	39 (3) = 42dB
$L'_{nt,w}$	36 (3) = 39dB
Height(s)	52mm, 42mm, 32mm
Insulation	25mm 20kg polyester 400mm x 38mm
Acousta Batten spacing	450mm centres
Tested	CSIRO TL1401, STR079

The Acousta batten is available in a range of depths 52, 42 & 32mm. The timber batten is encased in rubber. It is recommended that the batten be spaced at 450mm centres. The battens are clipped to the structure and insulation is required between the battens. The system requires laser levelling upon installation.

The supplier specifies a 5mm gap between Acousta batten and wall; 1mm gap between the timber flooring and skirting; and that timber floorboards must not touch any of the perimeter walls to reduce noise flanking and the recommended minimum gap is 5mm.

Suppliers of Acousta Batten have stated their product should perform within the field as low as 39dB. According to the tests that were conducted with System D, the Acousta Batten performed at L'_{nTw} (C_I) = 42 (4) or 46. This result was obtained with 19mm Bluegum Hardwood floorboards, Acousta Batten with insulation between on 180mm concrete slab, 150mm airgap to a suspended 13mm single layer plasterboard ceiling.

With promoting any product, the public needs to know the specific details that have culminated in this result. The entire system needs to be identified and explained i.e. thickness of the concrete, the size of the air gap between concrete and ceiling, the thickness of the plasterboard ceiling, as these all have an influence on the performance of the product in association with other materials.

2.18 SUMMARY – Chapter Two, Literature Review

According to Robert Caulfield of the RAIA, the problem of coping with noise and other privacy issues will only increase in the future. Renzo Tonin stated that with the increase in medium to high density living, so too has the venting of displeasure associated with poor acoustics.

It seems reasonable to assume the more we pay for an apartment, the higher the expectation is in terms of how well that unit needs to perform acoustically. To reiterate, good acoustical design isn't a luxury, it's a necessity, and acoustics impacts on everything, including market value (Janning, n.d.).

So the question arises, how can the purchaser really know how well a building performs acoustically, when they are purchasing either off the plan, or post- completion?

Answer: coupled with a building report perhaps, the purchaser can only surmise. It is not until a person lives in an apartment over a duration of time, can they satisfactorily know how well it performs.

There is currently no mandatory nationwide star rating that provides an indication of the performance of the building for the purchaser and/or the end user other than the star rating offered by the AAAC. Yet, when we wish to stay at a hotel, the performance of the hotel is always rated on a one to five star rating criteria. Why then should this not be applied to buildings?

Knowing the star rating of a hotel for example, where a person might spend $500 for one night is as important as knowing the rating of a unit where the outlay might be a thousand times more, e.g. $500,000 where the occupancy factor might be for a lifetime. When you think about the outlay and the investment period of the latter, the significance of the rating system would be a thousand times as important.

The world is moving towards being predominately urban rather than rural. It has been stated that during the last decade, an increase of 83% has occurred globally in towns and cities (HSC, CSU). To reiterate, we are now living and working closer to each other than ever before (Nova, 2002).

When new apartments are featuring expansive city, ocean or river views, large floor areas, sizeable balconies, individually controlled airconditioning systems, undercover security parking, storage, lap pools, gymnasium, health spas, commercial shops, key card security, concierges and the like, it is no wonder that the lifestyle is being preferred to the labour intensive quarter acre block (Bentley 1999). This is what is referred to as ‘Amenity’ or ‘Quality of Life’.

But an increase in amenity can also see increases in what is called ‘urban intensification’. It is this urban increase that has the potential to create what is being regarded as ‘unit rage’ where early retiring ‘empty nesters’ are mixed in with the 24 hour single party set (Fletcher, Soundblock, n.d.).

Australian data for impact noise transference is difficult to obtain as acoustic professionals espouse ‘commercial-in-confidence’. Suppliers are wary of revealing comprehensive and comparative results in order to maintain an edge within competitive markets and may only provide information on a ‘need to know’ basis. Data, if compiled, could provide indicators and valuable baseline data to establish more realistic benchmarks as a basis to influencing the current building code pertaining to acoustics (EPA, 2003).

We need to contain and reduce noise in order to enjoy a healthy life and reduce our impact on others, particularly in high density areas (Greenhouse). But little can be demanded of the building contractor if impact noise becomes an issue post-occupancy with disgruntled occupants when the acoustics has complied with the relevant code i.e. $L_{nTw} C_I$ 62 at time of approval.

Tolerating noise is highly subjective. Our tolerance varies according to the type of noise, our mood, time of day, background noise levels and our expectations. We also react to noise in various ways.

We take most sounds for granted, but when the ‘sound’ becomes a ‘noise’ it can be distracting, breaking concentration. When this happens, it is identified as unwanted. What is a sound to one person could be another person’s ticket to insanity (Fyfe, 2003).

Often it is not the pitch or the loudness that makes the noise annoying. Richard Dowell, a professor of audiology and speech science at the University of Melbourne and The Royal Victorian Eye and Ear Hospital, says ‘the most annoying sounds are the ones that we have little control over’ (Fyfe, 2003).

British noise pollution research suggests we get annoyed more easily because we are less neighbourly – having less social contact reduces our tolerance of neighbourhood noises. We are now decorating more sparsely, with a fondness of floorboards and tiles, indeed anything except carpets and heavy drapes that help block sound (Fyfe, 2003). To reiterate, the trend, as we are experiencing it, is that our cities are being built up rather than out. Because executive apartments are becoming more costly, our expectations are higher.

Exposure to excessive noise has been proven to cause hearing problems, stress, poor concentration, productivity losses in the workplace, communication difficulties, fatigue from lack of sleep, and a loss of psychological well-being (Nova, 2002).

According to McGowan's results within his chart titled 'Typical Noise Limits' (table 3), he states that within mainly residential areas, between 0700 – 1800 hours Monday to Friday, we should expect between 50 – 54 dB readings within our homes. Between the evening 1800 – 2200 hours the readings should be between 44 – 48 dB. At night between 2200 – 0700 hours the readings should be between 39 – 43 dB. On Sundays and public holidays between 0700 – 1800 hours the evening noise limits should apply of 44 – 48 dB. This is a vast difference to the BCA's compliance level of $L'_{n,w}$ C_I 62.

According to OSHA's noise thermometer, it indicates the threshold of audibility at 20dB a whisper at 30dB, 40dB is a quiet residential, library or office area, and a comfortable noise level range is 50dB.

The BCA's '62' rating is almost the equivalent of the sound that a sewing machine makes, a normal conversation or the rumble of a dishwasher. OSHA also regards 65 dB as being non-hazardous and the table indicates that the human ear can sustain noise levels up to 85 dB for duration of 8 hours.

A vacuum cleaner emits 74 dB, an alarm clock 75 dB, a ringing telephone 82 dB, but an ear piercing smoke alarm, particularly at close range, rings out an alarming 85 dB.

We would assume that these numbers are averages, as I am sure that different equipment varies in noise output. An extension of this study would be a comprehensive look into end user tolerances, for example, various levels of noise output up to 85 dB in a range of moods, time of day and personal ages.

By establishing an average tolerance level from a range of people, in a range of apartments categorised into the AAAC's star rating system, I believe this information would be of huge benefit when reviewing what is an acceptable noise level emission. This may address the issue of noise transmission in medium to high rise apartments in Australia where purchasers are more informed about what level of building they are buying. This may allow purchasers to purchase an apartment relative to their average tolerance level and have architects and builders design and build to the star rating that the market expects or demands.

CHAPTER THREE

RESEARCH DESIGN and METHODOLOGY

The planning, construction and statistical analysis of comparative field and laboratory tests.

3.1 INTRODUCTION

Acoustic Performance is arguably the most important experiential and non-visual discriminator of quality homes and apartments. Owners and tenants are becoming increasingly aware of good acoustic performance, the difference it can make and what it means for living comfort (Powerscape, 2005).

Achieving complete silence in buildings is virtually impossible, and fortunately absolute silence is not usually necessary for acoustic comfort or peace to be experienced. This may be necessary for music studios but not for a sole occupancy unit. Finding the level at which sound transmission is considered peaceful or non-irritating depends on many factors including individual preference, time of day, ambient noise etcetera, however, it is accepted that a considerable reduction in noise transmission makes for a more peaceful environment (Powerscape, 2005).

When discussing *impact sound* in relation to noise between apartments vertically, it is generally defined as the transfer of sound by impact caused by one object on another from one space to another because the impact causes both sides of the structural element to vibrate, which in turn generates sound waves.

Typical impact sound sources on hard surfaced floors are foot treading, jumping, vibrating appliances and dropped objects. When a surface is struck it causes a vibration. This vibration travels by structural association to other parts of the assembly where it culminates by radiating sound into the air. It is this impact noise that is interpreted as a negative irritating sound and the hard surfaces include not just tile and timber, but vinyl, that can accentuate sounds also. (Powerscape, 2005).

This chapter will discuss the most appropriate methodology, the type of research chosen including the intricacies between field and laboratory testing, data collection, processing, interpretation and the Australian Standards. Also included is a section that discusses the application of this research such as; research management, public relations, building quality, the BCA requirements and the code levels expected in other countries such as England, Wales and Scotland for both new and change of use buildings.

The Association of Australian Acoustical Consultants published their Star rating system in May 2005 that ranks the current Building Code of Australia impact requirements of 62 between the lower levels of 2-3 stars. This chart (illustrated on page 43) rates the acoustic performance of apartments from 2 to 6 stars (six being the best) and will be used in conjunction with the summary of the field and laboratory tests.

Interior photos of both the sending and the receiving rooms of the fully operated commercial acoustic laboratory in this country courtesy of the CSIRO in Melbourne are included in this chapter.

The basic purpose of this research is as follows:

- to measure differentials between laboratory tests to actual field tests;
- to assess the differences that various structural differences may have on acoustic performance; and
- to judge the effectiveness of various acoustic materials and systems used in construction.

Because the lab is a perfect environment that is rarely duplicated in everyday applications, some products will not test the same in the field. Certain factors, such as installation variables, and construction types, are not accounted for in the lab. A product that receives high performance ratings in the lab may not perform as well in the field.

This chapter will also discuss methods of testing and test results that have been conducted in countries other than Australia. According to Powerscape, small structural variations and installation detail differences can result in significant variations in acoustic performance.

3.1.1 Background

The $L_{n,w}$ (weighted normalised impact sound pressure level for laboratory testing) and $L'_{nT,w}$ (weighted standardised impact sound pressure level for field testing) are acoustic measures that have originated from International Standards, and the compliance level of ‘62’ has been adopted by the Building Code of Australia effective since May 1, 2004. When combined with the spectrum adaptation term C_I, the focus is to emphasise low frequency sounds affecting occupant satisfaction such as footsteps. The subscript “I” is for impact.

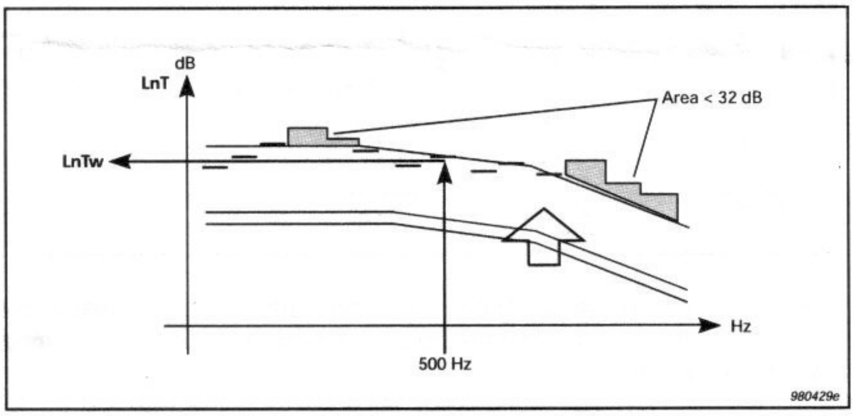
3.1.2 Test Methods

Although the two floor and laboratory test metrics are different, the underlying test method is essentially the same. A standard tapping machine impacts the source room floor. A microphone measures the sound level in the receiving room. As sound insulation changes with frequency, the receiving room sound level is measured at 16 one-third-octave band centre frequencies. The suggested frequencies range from 100Hz to 3150Hz.

Ordinarily, measurement data is adjusted to account for the characteristics of the receiving room, and is then plotted resulting in a measurement curve. A standard reference curve is then fitted to the measurement curve. Rules are followed (described in ISO 717.2) to fit the reference curve to the measurement curve to obtain a single number acoustic performance rating. (Powerscape, 2004)

3.1.3 Weighting

Building regulations specify limits not in terms of spectra, but as single-number quantities calculated from the L'_{nT} or L'_{nw} spectra. The calculating procedure is called weighting (see figure 5). The result is called the Weighted Standardised Impact Sound Pressure Level. (Bruel & Kjaer)



Source Bruel & Kjaer

FIGURE 6 - WEIGHTING & THE REFERENCE CURVE

Single number result (L_{nTw}) is calculated by shifting the reference curve upwards in 1 dB steps until the measured spectrum exceeds the reference curve by less than (but as close as possible to) a sum of 32 dB. The weighted result is the value of the reference curve at 500 Hz. For $L_{n,}$ the weighting procedure is similar, resulting in the Weighted Normalised Impact Sound Pressure Level.

3.2 SELECTING A METHODOLOGY

Detailed acoustic results pertinent to class 2 buildings are difficult to obtain due to 'commercial-in-confidence' and therefore it has been necessary to conduct field and/or laboratory tests independent of any commercial influence with the understanding that any tests will be in line with *tertiary ethics*. In order to keep open the opportunity to accept tests from builders/developers/acoustic specialists or acoustic product companies not shy in allowing their results to be published, it is also imperative to respect their sensitivity and confidentiality.

Simulations are often conducted in laboratories because they offer controlled conditions. It is this 'control' offered by laboratory experiments, combined with the realistic conditions offered by field work, that often creates a need for both forms of experimentation to be utilised simultaneously, in order to satisfy a research aim (Holt, 1998). Simulations see how the same material(s) and/or system(s) perform both in the laboratory and field. This enables the possibility to gauge the differentials and understand the variables involved.

3.3 TYPE OF RESEARCH

'A sceptical attitude lies at the root of all good experimental work,
and should be consciously cultivated' (Wood and Martin, 1974).

The following types of research have been identified and considered; exploratory, descriptive, hypothesis testing, comparative, cross-sectional, longitudinal, cross-cultural, strategic, survey, experimental, quasi-experimental, case study, qualitative, **quantitative, field testing, laboratory testing,** applied, public opinion, election, marketing, mass communication, policy, evaluation, forecasting, group, organization, demographic, and applied behavioural.

The range of styles of research that this thesis has chosen falls into a number of categories namely those highlighted above:

- comparative;
- quantitative; and
- field and laboratory testing.

3.3.1 Comparative

Comparative studies are defined as two or more existing situations studied to determine their similarities and differences. During the development and use of comparative methodology several issues become apparent with the design and application:

- technical effort;
- varied situations; and
- complicated analysis.

Technical effort: will take into account setting up the acoustic equipment on site, any peculiarities of the site in terms of access, the structure type i.e. column and slab, load bearing walls and post tensioned concrete, the choice of materials used in the construction, and any difficulties encountered with conducting the tests.

It will be necessary to keep a research diary, a log book or a completed document such as a 'report proforma' to record the tests being conducted in order to meticulously record the particulars of the methods used both in the field. This will culminate in the information being collated and formulated against the curve of reference values (ISO 717-2) and $L'_{nT,w} + C_I$ and compared against the BCA requirement of $L_{n,w}$ 62.

It will be necessary to extract the acquired data as soon as practicable and back-up the information to limit the chances of data loss and write up the report to formulate conclusions.

Varied situations: it will be necessary to record any differences in the environment eg. structure type, ceiling heights, volume (space), time of day, nature of the day, set up and testing process.

Complicated analysis: an explanation of how the data was analysed and any methodological problems encountered, explanations required, or considerations necessary and the resulting solutions. Any problems anticipated or experienced will be discussed and the steps taken explained to either prevent them from occurring, or the problems that did occur and the ways their impact on the study was minimized. The most salient findings from such analysis will be presented and discussed.

3.3.2 Quantitative

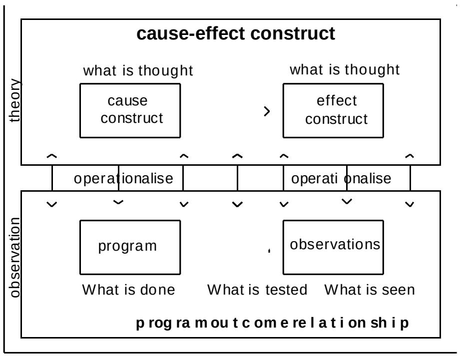
This research will be largely reliant upon quantitative analytical data i.e. structured testing in accordance with current Australian Standards for acoustic testing. In saying this, qualitative and quantitative data *are* intimately related to each other. *All quantitative data is based upon qualitative judgements* and what might seem a straightforward, simple, cut and dried quantitative series of acoustic tests, will also be reliant upon qualitative judgements in relation to assessing those tests (Trochim, 2001).

The aim of a quantitative research strategy is to objectively measure variables of identifiable issues (McCarthy, 2005). A rich explanation of quantitative research can be defined as “an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the hypothesis or the theory holds true” (Naoum, 2001). In this case the inquiry will be to judge the acoustic performance of acoustic and building systems both in the laboratory and in the field.

Quantitative data is collected and analysed by comparing and contrasting alternatives and differing situations. The data collected will be collected or generated in a way consistent with accepted practice.

According to Trochim, *the cause and effect construct* shows that two realms are involved in research. The first is the land of theory whereby in this case it is assumed that there are differentials between laboratory and field tests of the same system. The second is observation i.e. The real world of translating ideas such as the acoustic tests, measurements and observations.

TABLE 7 - CAUSE EFFECT CONSTRUCT



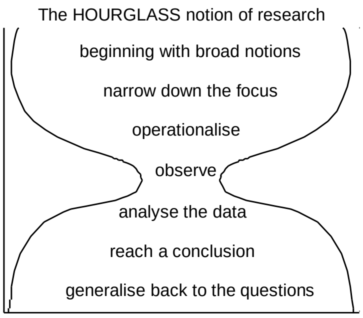
(Trochim, 2002)

It is this cause effect construct that will form the basis to testing the theory of the ‘extent of the differentials’ between laboratory versus field tests. Tests that put a theory into practice, by setting a program and putting that program into effect. It will be necessary to meticulously measure and record ‘what is done’, ‘what is tested’ and ‘what is seen’ through observation to reach a fully informed conclusion by understanding what variables are in play. The extent of the understanding forms the basis to the recommendations and solutions.

3.3.3 Field and Laboratory Testing – Physical Testing

The testing process of the physical world phenomenon will be in accordance with the relevant Australian Standards with the understanding that the tests might be time consuming to design, conduct, record and analyse (Holt, 1998).

TABLE 8 - THE HOUR GLASS NOTION OF RESEARCH



(Trochim, 2002)

According to Trochim, at the narrowest point of the research hourglass, the research is engaged in direct measurement or observation of the question of interest. A constant questioning system occurs in this diagram. When this diagram is applied to this body of research, the differentials between laboratory tests to actual field tests will be measured and the differences assessed. In doing this it will be possible to judge the effectiveness of the acoustic systems or construction types and therefore formulate some notions about the tests (under the various test conditions) prior to forming any final conclusions. This diagram illustrates the constant circle of reflecting .

3.4 DATA COLLECTION

Where the structure type in the field does not directly compare to a construction type tested in the laboratory and the problem arises whereby a direct comparison cannot be drawn, it may be necessary to construct the required building system either in the laboratory or in the field to enable a direct comparative or to rely on existing tests conducted by acoustic professionals or product companies. This would enable a direct comparison of the structure and materials (to be identified as A, B, C or D). The systems will need to be in accordance with the Australian Standards for laboratory or field testing.

If testing both areas, it may be necessary to utilise the same equipment and acoustic engineer, or when it is not possible to use the same acoustic specialist, to utilise the same methods when comparing the field to laboratory testing, so that the equipment, methods, techniques and any particulars for testing can also directly equate.

The research will require tests within the laboratory and/or field to be in accordance with the following Australian Standards:

1. AS ISO 140.6:2006

Acoustics – Measurement of sound insulation in buildings and of building elements.
Part 6: Laboratory measurements of the reduction of impact sound insulation of floors.

SCOPE

This part of ISO 140 specifies a laboratory method for measuring impact noise transmission through floors by using a standard tapping machine. The method is applicable to bare floors.

The results obtained can be used to compare the impact sound insulation properties of floors and to classify floors according to their sound insulation capabilities.

IMPACT RATING

$L_{n,w} + C_I$

This laboratory rating only applies to assemblies that have been constructed in a purpose-made acoustic laboratory and tested according to the ISO 140.6 standard. It applies to impact transmission from a standard tapping machine. The laboratory is designed so sound is measured vertically with sound from other paths, such as flanking, suppressed.

$L_{n,w}$ is the “weighted normalised impact sound pressure level”. It is a single number rating. In general, a lower number means better overall impact performance (the sound pressure level is lower). The rating is derived from data that has been adjusted (normalised) to receiving room absorption of $10m^2$ to account for the influence a receiving room has on sound pressure level.

C_I is a spectrum adaptation term. It effectively adjusts $L_{n,w}$ to account for typical footstep noise. The subscript “$_I$” is for impact.

By way of example, an $L_{n,w}$ of 56 and C_I of 3, may be reported as $L_{n,w} + C_I = 59$, or sometimes as $L_{n,w}$ (C_I) 56(3).

(PLEASE REFER TO APPENDIX 1)

2. AS/NZS ISO 140.7:2006

Acoustics – Measurement of sound insulation in buildings and of building elements Part 7: Field measurements of impact sound insulation of floors (ISO 140-7:1998, MOD).

SCOPE

This part of ISO 140 specifies field methods for measuring the impact sound insulation properties of building floors by using a standard tapping machine. The method is applicable to bare floors.

The results obtained can be used to compare the impact sound insulation properties of floors and to compare the apparent impact sound insulation of floors with specified requirements.

IMPACT RATING

$L'_{nT,w} + C_I$

A field rating that only applies to assemblies that have been tested on site according to ISO 140.7. It can apply to impact transmission from a standard tapping machine in vertical, horizontal and diagonal directions. Performance can be affected by other sound paths, for example through the structure and down the walls, an effect known as 'flanking'.

$L'_{nT,w}$ is the “weighted standardised impact sound pressure level”. The rating is derived from data that has been adjusted (standardised) to a receiving room reverberation time of 0.5 seconds to account for the influence the receiving room has on sound pressure level.

C_I is a spectrum adaptation term. It effectively adjusts $L_{n,w}$ to account for typical footstep noise. The subscript “$_I$” is for impact.

(PLEASE REFER TO APPENDIX 2)

3. AS ISO 717.2:2004

Acoustics – Rating of sound insulation in buildings and of building elements. Part 2: Impact sound insulation.

SCOPE

This part of ISO 717 defines single-number quantities for the impact sound insulation in buildings and of floors; gives rules for determining these quantities from the results of measurements carried out in one-third-octave bands in accordance with ISO 140-6 and ISO 140-7, and in octave bands in accordance with that option in ISO 140-7 for field measurements only; and defines single-number quantities for the impact sound reduction of floor coverings and floating floors from the results of measurements carried out in accordance with ISO 140-8.

The single-number quantities in accordance with the part of ISO 717 are intended for rating the impact sound insulation and for simplifying the formulation of acoustical requirements in building codes. The required numerical values of the single-number quantities are specified according to varying needs.

PLEASE REFER TO APPENDIX 3

3.5 DATA PROCESSING AND INTERPRETATION – Field Testing

3.5.1 Data processing

A summary of the single number rating ($L'_{n,w}$ – weighted normalised impact sound pressure level and C_I – spectrum adaptation term for impact sound level) is adjusted in accordance with AS/ISO 717.2: 2004 Acoustics – Rating of sound insulation in buildings and of building elements – Part 2 Impact sound insulation.

3.5.2 Equipment use

A standard 'Tapping Machine' produces a known force (mass x acceleration) at a known repetition rate using standard AS/NZS ISO 140.7:2006. The tapping machine is positioned on the floor within the receiving room in at least **four different positions** distributed on the floor as defined in ASTM E1007 (indicated next page in Fig. 5).

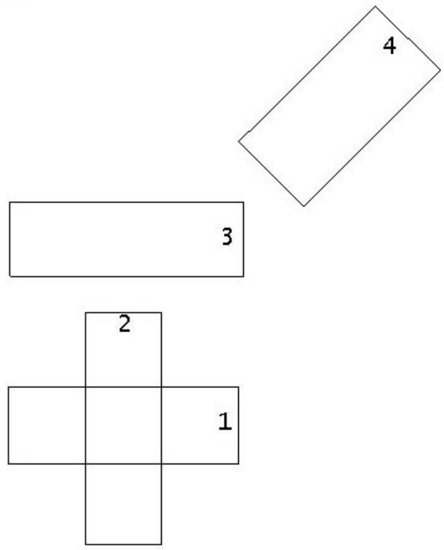


FIGURE 7 – TAPPING MACHINE POSITIONS 1-4

The distance of the tapping machine from the edges of the floor shall be at least 0,5 m. In the case of anisotropic floor constructions (flooring with ribs, beams, etc.) more positions may be necessary.

IMPACT DEVICES USED IN RESEARCH

3.4.2.1 Tapping Machine Bruel & Kjaer 3207

The tapping machine is a lightweight portable impact sound source designed to fulfil the specifications of the standards dealing with impact sound transmission measurements. It is useable for a range of standards including ISO 140, ASTM E 492, DIN 52210, BS 5821 and ISO 717.

The personal computer based software measurement system used to generate the results is the Bruer and Kjaer ‘Qualifier’ and with this building acoustics software, the weighted impact sound pressure level is calculated.

The tapping machine is made of five steel hammers in line, weighing 0.5 kg each. It provides a free fall of the hammers equal to 40 mm, as required by the Standards. A motor and cam system drives these to strike the floor a total of ten times per second (10Hz).

User-interchangeable rubber tipped hammers for special floors is available as an option, particularly for soft-timbers or a newly laid tile floor.

Installing the tapping machine on-site is very simple. Battery operation ensures freedom of use. A remote control allows the user to operate the tapping machine at a distance during a measurement session in order to limit the duration of the impacts. (Acu-Vib Electronics)

3.4.2.2 TECHNICAL SPECIFICATIONS

Power: 220 Volts AC – Working 12 Volts DC

Electronic control of impact rate

Battery life: about 1 hour

Radio control for remote operation

Weight: approx 15kg

Dimensions: 810mm x 330mm x 320mm

3.4.2.3 MECHANICAL FEATURES

Five steel hammers in line

Free fall equal to 40mm (adjustable)

Tapping frequency: 10 impacts per second – 10 Hz

Time between impact and lift of the hammer – less than 80 m/s

3.4.3 JAPANESE STANDARDS and the TIRE DROP TEST

To deal with the problems of footstep noise on lightweight floors, the Japanese Standards Organisation (JIS) has developed test procedures for light impact sources as well as the tapping machine test for heavy impact source.

The standards they have are as follows:

<u>JIS A 1418-1:2000</u>

Acoustics – Measurement of floor impact sound insulation of buildings – Part 1: **Method using standard light impact source**; and

<u>JIS A 1418-2:2000</u>

Acoustics – Measurement of floor impact sound insulation of buildings – Part 2: Method using standard heavy impact sources.

Their floor impact standard is: JIS A 1419-2:2000; and their laboratory testing standard is: JIS A 1440:1997.

A small automobile tire is dropped from a height of 0.9 m onto the floor under test, and sound pressure levels are measured in the room below. Most of the energy generated by this impact is at low frequencies.

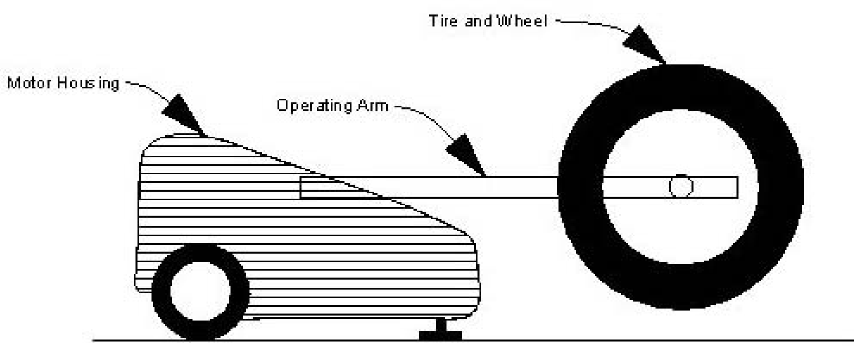


FIGURE 8 - SKETCH OF THE RION BANG MACHINE (not to scale)

Conversations with Japanese research workers have revealed that there is some dissatisfaction with the Japanese test. Alternatives are being investigated in Japan (6-Warnock).

3.4.4 LIVE WALKERS

One criticism made of the standard tapping machine is that the steel hammers do not properly simulate a human foot. It is common in research into footstep noise to use one or more walkers as a reference. Although there is no standard method for measuring the sound pressure levels generated by a person walking on a floor, certain techniques are used to accommodate a 'standard walker'.

According to Warnock, in the 1990s committee members of the ASTM recognised that a single microphone position could be used when measuring peak sounds from either single hammer impacts or footsteps. The microphone is placed 1000mm below the mid-point of the ceiling and the room below is made less reverberant by placing sound absorbing material in it until the reverberation time is about 0.5 seconds. Although the technique has not been standardized it is used in laboratories for measuring walker, ball and tire levels. The single microphone technique should be adequate for comparison of floors tested within a single laboratory when peak levels are being measured.

Professor Warnock has established a standard walker, a male weighing in at between 85 - 90 kg. The walker is required to generate a constant sound pressure level when walking on the floor. The walker is required to walk for approximately three minutes either in a figure eight or in a circle while the maximum sound levels for 100 footsteps per minute are collected using a 35ms time constant. (2-Warnock, 1998)

The type of shoe worn has an influence on the noise generated during walking and the shoes required needs to be leather, both in sole and heel.

This series of tests will, in addition, take the liberty of comparing a live male walker of approximately 85kg with leather shoes to a 60kg female walker with synthetic high heels.

PHOTOGRAPH 1 – MAN'S LEATHER SOLED SHOES

PHOTOGRAPH 2 – WOMENS HIGH HEEL SYNTHETIC SHOES

3.4.5 EXPERIMENTAL RUBBER BALLS

According to Warnock, H. Tachibana, a Japanese researcher in this field, developed the use of rubber balls as part of a research program (2-Warnock,1998). Tachibana used two balls approximately 180mm in diameter weighing 2.5 kg each. The first ball was less resilient than the second ball and both were dropped from a height of 900mm at random positions in the middle of the floor. The force generated was sufficiently repeatable that only 15 impulses needed to be collected and averaged.

The advantages of the balls are that they offer simplicity of operation, zero maintenance and portability and most definitely cheaper than a tapping machine.

The 2.5kg ball used in these series of tests is a 110mm wide, 2.5kg rubberised Grip Ball made by AOK Health. It is a fully filled sand ball and does not bounce. The reason why a smaller sized ball was chosen compared to the balls used by H. Tachibana is because the sound generated by the 2.5kg solid sand ball sounded more significant i.e. the solid ball did not give a hollow resonance and is believed to closely assimilate sounds generated through floors in living quarters.

PHOTOGRAPH 3 – 2.5kg GRIP BALL

3.4.6 TABLE 9 – TEST EXAMPLE (laboratory)

(All references to product names, institutions or companies have been omitted for purposes of confidentiality.)

Normalized Impact sound pressure levels according to ISO 140-6
Laboratory measurements of impact sound insulation of floors

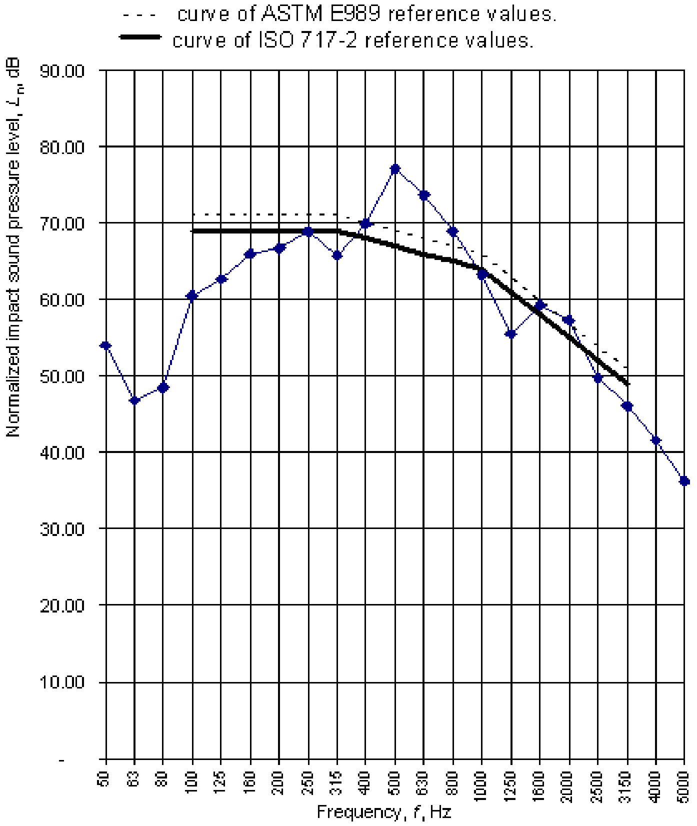
Test rooms: Chambers A and B

Description and identification of the test specimen and test arrangement:

8mm thick tile adhered to 10mm acoustic underlay adhered with 8mm notched trowell on 140mm concrete slab

Area *S* of specimen floor: 10.24 m^2
Receiving room volume: 153 m^3

Frequency *f* Hz	L_i One-third octave dB
50	54.0
63	46.8
80	48.5
100	**60.6**
125	**62.7**
160	**66.0**
200	**66.7**
250	**68.9**
315	**65.8**
400	**69.9**
500	**77.1**
630	**73.7**
800	**68.9**
1000	**63.3**
1250	**55.5**
1600	**59.3**
2000	**57.3**
2500	**49.8**
3150	**46.1**
4000	41.6
5000	36.3



Notes: #N/A = Value not available. **Bold** values are used to calculate IIC and $L_{n,w}$.
< indicates that the true value is lower.

Rating according to ISO 717-2:

$L_{n,w}$ (C_I) = 67 (-1) dB $C_{I,50\text{-}2500}$ = -1 dB

Rating according to ASTM E989:

Impact Insulation Class = 41 dB

Evaluation based on laboratory measurement results obtained by an engineering method.

The example given for the laboratory measurements of impact sound insulation of floors, for the 8mm thick tile to 10mm acoustic underlay adhered with 8mm notched trowel on 140mm concrete slab, indicates the test results recorded in one-third octaves. The specimen floor area is identified and the volume of the receiving room recorded. The results are graphed in relation to the reference values and the rating is given in accordance with ISO 717-2.

3.4.7 Generation of Sound Field

Impact sound pressure levels may reveal a time dependency after the tapping is started. In such a case the measurements should not begin until the noise level has become steady.

3.4.8 Types of Variables

- microphone positions
- position(s) of the tapping machine

The variables that can influence the performance of systems or acoustic materials in the field are as follows:

- thickness of the slab
- thickness of the timber floor structure
- joist type, spacing and depth
- air space cavity
- insulation density
- volume and configuration of the room(s)
- time of day and temperature variants
- background noise levels i.e. external traffic, wind and rain
- building structure types and various acoustic systems
- construction quality
- surface treatments and materials within the rooms
- penetrations
- noise flanking

Relative variables will be noted at the time and will be discussed within the analysis.

3.4.9 Levels of analysis

The transmitted impact sound is characterised by the one-third octave band spectrum of the average sound pressure level produced by the tapping machine in the receiving room below. The information is recorded using acoustics software and analysed by the Bruel & Kjaer sound analyser.

Adjustments are made for the measured reverberation time of the receiving room and adjustments as necessary for background noise.

3.5 APPLICATION OF RESEARCH

3.5.1 Research Management and Relations

It will be necessary to furnish the developer / builder / sales agent with information regarding the processes involved with the test procedures and the reasoning for the tests. It will be necessary to inform the developer / builder / sales agent that confidential data and research records (i.e. background and statistical information relevant to the research) will be stored in a secure location for five years following the completion of the research unless they choose otherwise, and at the culmination of that period the material will be shredded/destroyed.

Written consent will be necessary from the developer / builder / sales agent that allows comment to specify any requirements particular to the building site to comply with access, time constraints, safety considerations, site-specific inductions, etc.

3.5.2 Public Relations

Feedback will be provided to stakeholders and/or contributing participants on the overall results of the project.

Written response will include:

- information about the test pertinent to their building or product; and
- comparisons to either the laboratory test or field test and the processes undertaken as per the Australian Standard.

3.5.3 Organisation of Research

Once the methodology is complete and satisfactory and the commitments met in relation to *ethics*, then the sites and/or systems for laboratory testing can be organised and set up and the testing process can begin with the appropriate approvals.

Following this will be analysis and discussion of the results followed by a conclusion and recommendations for further research.

3.5.4 Reporting Research and Evaluation

It is an expectation that the research culminate in a publishable paper for both the CIOB in Australia and United Kingdom and the ABCB in Canberra, Australia.

3.6 ASSUMPTIONS

3.6.1 Concrete Slabs

Joints between concrete slabs or panels and any adjoining construction (it will be assumed) must be filled solid.

3.6.2. Timber or Steel-framed Construction

Perimeter framing members must be securely fixed to the adjoining structure and bedded in resilient compound; or the joints must be caulked so that there are no voids between the framing members and the adjoining structure.

3.7 BUILDING CODE of AUSTRALIA 2004

The Building Code of Australia allows compliance to be demonstrated in a number of ways including laboratory test results, site tests and expert opinion. (The following information is extracts from the Building Code of Australia, and have been supplied with the permission of the Australian Building Codes Board).

3.7.1 Definition

'Class 2 buildings (a building containing 2 or more *sole-occupancy units* each being a separate dwelling)'.

3.7.2 Performance Requirements

FP5.1

'Floors separating –

(a) *sole-occupancy units*: or

(b) a *sole-occupancy units*, from a plant room, lift *shaft*, stairway, *public corridor*, public lobby, or the like, or a part of a different classification.

must provide insulation against the transmission of impact generated sound sufficient to prevent illness or loss of amenity to the occupants'.

FP5.3

'The *required* sound insulation of a floor must not be compromised by-

(a) the incorporation or penetration of a pipe or other service element; or

(b) a door assembly'.

FP5.6

‘The required sound insulation of a floor or a wall must not be compromised by the incorporation or penetration of a pipe or other service element’.

VERIFICATION METHODS

FV5.1

‘Compliance with FP5.1 and FP5.3 to avoid the transmission of airborne and impact generated sound through floors is verified when it is measured in-situ that the separating floor has –

(a) airborne: a weighted standardised level difference with spectrum adaptation term ($D_{nT,w} + C_{tr}$) not less than 45 when determined under AS/NZS 1276.1 or ISO 717.1; and

(b) impact: a weighted standardised impact sound pressure level with spectrum adaptation term ($L_{nT,w} + C_{I}$) not more than 62 when determined under AS/ISO 717.2‘.

3.7.3 PART F5 SOUND TRANSMISSION AND INSULATION

F5.0 Deemed-to-Satisfy Provisions

(a) Where a *Building Solution* is proposed to comply with the *Deemed-to-Satisfy Provisions*, *Performance Requirements* FP5.1 to FP5.6 are satisfied by complying with F5.1 to F5.7.

(b) Where a *Building Solution* is proposed as an *Alternative Solution* to the *Deemed-to-Satisfy Provisions* of F5.1 to F5.7, the relevant *Performance Requirements* must be determined in accordance with AO.10’.

F5.1 Application of Part

The *Deemed-to-Satisfy Provisions* of this Part apply to Class 2 & 3 buildings and Class 9c *aged care buildings*.

F5.3 Determination of impact sound insulation ratings

(a) A floor in a building *required* to have an impact sound insulation rating must –

(i) have the *required* value for weighted normalised impact sound pressure level with spectrum adaptation term ($L_{n,w} + C_{I}$) determined in accordance with AS/ISO 717.2 using results from laboratory measurements; or

(ii) comply with Specification F5.2'.

The forms of construction listed for floor construction are considered to have the R_w, $R_w + C_{tr}$ and $L_{n,w} + C_I$ stated in the following table. (The quality of construction is assumed to be of acceptable construction).

3.7.4 TABLE 10 – ACCEPTABLE FORMS OF CONSTRUCTION FOR FLOORS

'Building Code of Australia 2004 – Table 3 courtesy ABCB'

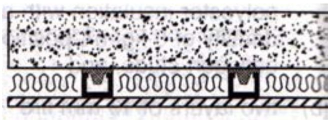
	Description	$R_w + C_{tr}$ (not less than)	$L_{n,w}+C_I$ (not more than)	R_w (not less than)
Floor construction type: Concrete				
1. 150mm thick concrete slab with:				
(a)	28mm metal furring channels and isolation mounts fixed to underside of slab, at 600mm centres; and	50	**62**	50
(b)	65mm thick polyester insulation with a density of 8kg/m3, positioned between furring channels; and			
(c)	One layer of 13mm plasterboard fixed to furring channels			
2. 200mm thick concrete slab with carpet on underlay		50	**62**	50
3. 100mm thick concrete slab		45	-	45
Floor construction type: Autoclaved aerated concrete				
4. 75mm thick autoclaved aerated concrete floor panel with:				
(a)	8mm ceramic tiles with flexible adhesive and water proof membrane, located above the slab; and	50	**62**	50
(b)	Timber joists at 600mm centres; and			
(c)	R1.5 glasswool insulation positioned between timber Joists; and			
(d)	28mm metal furring channels and resilient mounts fixed to underside of joists; and			
(e)	Two layers of 13mm plasterboard fixed to furring channels			
Floor construction type: Timber				
5. 19mm thick chipboard floor sheeting with:				
(a)	190 x 45mm timber joists at 450mm centres; and	50	**62**	50
(b)	R2.5 glasswool insulation positioned between timber Joists; and			
(c)	28mm metal furring channels and isolation mounts fixed to underside of joists, isolation mounts to be of natural rubber with a dynamic factor of not more than and static deflection of not less than 3mm at actual operating load; and			
(d)	Two layers of 16mm fire-protective grade plasterboard Fixed to furring channels			
6. 19mm thick tongued and grooved boards with:				
(a)	Timber joists not less than 175mm x 50mm; and	-	-	45
(b)	75mm thick mineral insulation or glass wool insulation with a density of 11kg/m^3 positioned between joists and laid on 10mm thick plasterboard fixed to underside of joists; and			

(c)	25mm thick mineral insulation or glass wool insulation with a density of 11kg/m^3 laid over entire floor, including tops of joists before flooring is laid; and			
(d)	Secured to 75mm x 50mm battens; and			
(e)	The assembled flooring laid over the joists, but not fixed to them, with the battens lying between the joists.			

(source: Diagrams provided courtesy of the Australian Building Codes Board)

3.7.5 FIGURE 9 – CONSTRUCTION DETAILS (BCA 2006)

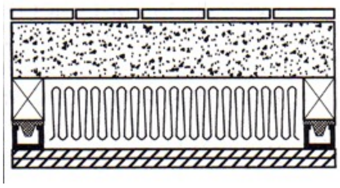
Floor construction type: Concrete with furring channel, insulation and plaster ceiling



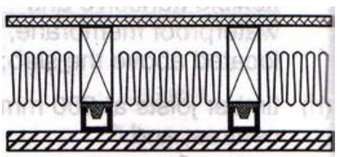
200mm thick concrete slab with carpet on underlay

100mm thick concrete slab

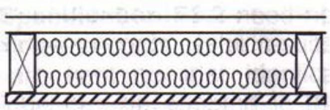
Floor construction type: *Autoclaved aerated concrete with batten, furring channel, insulation and two layers of plasterboard ceiling*



Floor construction type: Timber: *19mm thick chipboard floor sheeting with timber joist, furring channel, insulation and two layers plaster ceiling*



Floor construction type: Timber: *19mm thick tongued and grooved boards, timber joist, two layers insulation and single plaster ceiling*



3.8 CONCRETE STRUCTURES

Concrete structures transmit impact sound readily particularly if the slab is anywhere between 180-250mm in depth. To minimise this effect, they require the installation of an effective acoustic underlay to the floor surfaces. Sound transmission through concrete floors can be reduced with thicker slabs, (Powerscape) with insulation and resilient mount systems coupled with either carpet and underlay or an acoustic pad between the surface material and the concrete.

When hard floor finishes including tiles, timber and even vinyl are adhered directly to concrete floors, impact sound can readily pass through these materials into the concrete structure of the building. Once sound penetrates it can pass freely throughout the building across apartments horizontally and vertically.

3.8.1 Acoustic Floor Underlay to Concrete Floors

Acoustic floor underlays are normally placed on top of the concrete floor. The final floor finishing material is then placed over the acoustic underlay. Because the underlay acts close to the noise source the noise reducing material reduces the transmission of impact sound from the floor and into the concrete building structure. As less sound gets into the structure, less sound therefore reaches the rooms below. (Powerscape, 2005)

3.8.2 High Acoustic Comfort

Acoustic comfort can be enhanced through any or all of the following:

- by placing insulation in the ceiling cavity (between the underside of the floor structure and the plasterboard / ceiling);
- by increasing the ceiling cavity depth; and
- by placing an acoustic barrier between the surface material and concrete slab;
- by utilising a resilient mount in the ceiling system;
- by increasing the depth and/or density of the slab.

The thicker the concrete slab and the cavity ceiling coupled with an acoustic barrier the better the results in terms of improved acoustic performance. Increasing the cavity depth and including insulation all adds to higher performance.

3.9 WOOD FRAME STRUCTURES

According to Dr. A Warnock of the National Research Council Canada, plasterboard attached directly to the underside of joists or to metal furring attached directly to the floor structure gives poor impact sound attenuation. A basic timber joist floor that follows good acoustic principles is one that has a suspended resilient mount between the metal furring channel supporting the plasterboard and sound-absorbing batts in the cavity.

Joist floors must still have a finish layer, and an unwise choice can actually increase sound transmission. Hard finishes such as ceramic tiles adhered directly to the subfloor, for instance, reduce acoustic performance by increasing the transmission of sharp, high-frequency sounds. Thin resilient coverings, such as vinyl, while reducing the sharpness of noise, do not greatly increase the performance of joist floors.

For floors incorporating resilient metal channels (also known as resilient mount systems) and sound absorbing material (insulation and/or acoustic material), Dr A. Warnock of the NRCC states again that predications can be made to determine the sound transmission class (STC) and impact insulation class (IIC) with sufficient accuracy by simple regression analysis using variables such as the mass of the layers, joist depth and spacing, insulation thickness, density and resilient metal furring spacing. (5-Warnock 2000)

3.10 (Resistance to the Passage of Sound for new and change of use buildings)

Dwelling-houses, Flats and Rooms for Residential Purposes (Aerodynamic) **TABLE 11 – COMPARATIVE BUILDING REGULATIONS – ENGLAND & WALES**

Test Type	New Build	Material Change of Use (conversion)
Impact for Floors	Max. $L'_{nT,w}$ 62	Max $L'_{nT,w}$ 64

3.11 (Resistance to the Transmission of Sound) (Aerodynamic)

TABLE 12 – COMPARATIVE BUILDING REGULATIONS SCOTLAND

Test Type	New Build & Material Change of Use (conversion)
Impact for Floors	Max. $L'_{nT,w\ (mean)}$ 61

The Australian requirement of 62 is comparable to England, Wales and Scotland. When rated in accordance with the AAAC, Bruel & Kjaer's Perception of impact noise in dwellings as a function of impact sound insulation (adapted from PWI: Schaololschutz im Hochlau, Maienfeld, 1997, these figures in the 60's seem less than ideal.

According to Bruel & Kjaer, “In many countries, present building regulations operate with a limit of around 53 dB”.

3.12 ASSOCIATION OF AUSTRALIAN ACOUSTICAL CONSULTANTS (AAAC)

3.12.1 Acoustical Star Ratings for Apartments and Townhouses

According to the AAAC, the Building Code of Australia (BCA) regulates minimum acceptable construction standards for buildings. It does not deal with other acoustic issues such as background noise intrusion from outside or noise generated by building services.

Although the BCA sets minimum standards, many members of the housing industry have interpreted these as absolute requirements, applicable to all types of dwellings. The result has been that owners of luxury apartments built to BCA standards have become dissatisfied with acoustic performances, which in their view are not commensurate with prices often paid i.e. in the millions (AAAC 2004).

3.12.2 The Star Rating System

The AAAC believes that to fulfil a need identified by the community, the housing industry and by other member firms of the AAAC, the following rating system has been prepared to rank the acoustical quality of apartments. This has been done to promote better standards of acoustical quality in apartments. This guide has been prepared principally by and for AAAC members. It is anticipated that the information may also be of use to others involved in the design, development and purchase of apartments / townhouses.

TABLE 13 – AAAC STAR RATING SYSTEM

Inter-tenancy Activities Impact Isolation of Floors		2 Star	3 Star	4 Star	5 Star	6 Star
Between tenancies	$L_{nT,w} \leq$	65	55	50	45	40
Between all other spaces and tenancies	$L_{nT,w} \leq$	65	55	50	45	40

Inter-tenancy activities generate a wide range of different noises including impact/structure-borne noise such as footsteps on hard floors, scraping chairs, the vibration of wall mounted clothes driers, the operation of kitchen appliances on kitchen benches and, the dropping of objects. For these types of noise the weighted standardised impact sound pressure level as indicated above has been adopted. A reduction in this parameter corresponds to an improvement in impact isolation. This replaces Impact Insulation Class (IIC) which was in common use in Australia.

NOTE There is no relationship between IIC (laboratory) and FIIC (field) and $L_{n,w} + C_I$ or $L'_{nT,w} + C_I$ respectively. These measures use different frequency ranges along with different curves and curve fitting rules.

3.12.3 Scoring System

The AAAC classification rating is determined by the lowest score awarded. Ideally scores should be given for not only impact sound but also for Services Noise Insulation as well as Airborne Sound Insulation. That investigation is beyond the scope of this research.

3.13 CSIRO ACOUSTIC LABORATORY, MELBOURNE (source room)

Interior of the sending or source room within the CSIRO Acoustic Laboratory in Melbourne, the tapping machine sits on a sample of carpet and the slab is 150mm thick.

PHOTOGRAPH 4

3.14 CSIRO ACOUSTIC LABORATORY, MELBOURNE (receiving room)

Interior of the receiving room (basement page 59) with Rotating Microphone Boom within the CSIRO Acoustic Laboratory in Melbourne. The top of the photo shows the underside of the test slab (source: CSIRO).

PHOTOGRAPH 5

Not everyone has the opportunity to see a fully professional commercial acoustic laboratory in operation, and the photographs are sufficiently clear to illustrate a section of red carpet beneath the tapping machine. It may be this laboratory that is utilised when seeking to test a particular floor / ceiling system.

3.15 RESEARCH CONFIDENTIALITY

The importance of maintaining research confidentiality whilst gathering and obtaining the appropriate data cannot be underestimated. The principle of voluntary participation requires that people not be coerced into participating in research. Closely related to the notion of voluntary participation is the requirement of informed consent whereby prospective participants must be fully informed about the procedures and risks involved in research and must give their consent to participate (Trochim, 2002).

This research guarantees the participants confidentiality. They are given assurance that identifying information will not be made available to anyone who is not directly involved in the study and any identifying factors will be kept in a secure location for five years and destroyed thereafter.

3.16 CONCLUSION

Dr. A.C.C. Warnock who is a senior researcher in the Indoor Environment Program of the Institute has done extensive research over the years in Canada with the National Institute for Research in Construction, and this information is available publicly.

Government research into how Australian structures perform acoustically provides not a lot of funding. When you compare what information is available publicly in Australia, it is vastly destitute compared with the information that proliferates from Canada.

Dr Warnock has managed to test as many as 190 lightweight joist floors with different joist types, sub-floors, ceiling types, ceiling support systems and so on. Because of Australia's building construction is similar to Canada, it would be an interesting exercise to draw comparisons conducted by the NRC to acoustic performance between structures of a similar types, materials and systems from Australia.

Although this body of research does not extend itself to a series of tests of that magnitude, it is encouraging to see tests to that degree are being conducted in other countries, and that other methods of testing are being considered.

This research indicates the intent to use a standardised tapping machine to examine the extent of the differentials between laboratory and field tests, between various structure types and their effectiveness. It proposes comparing live walking scenarios and 2.5kg ball drops in conjunction with industry standard tapping tests. The walking and ball drops are an effort to see how closely the various test methods can simulate actual noises from and within apartments and whether the dB levels are in deed acceptable.

Knowing and identifying the variables and how they can influence acoustic performance will go a long way in the understanding of how structural variations and installation details can make a difference. This study can only give a broad outline of what to expect in the most basic of scenarios. To be able to predict performance levels of complete systems, extensive study would be required which would be beyond the scope of this study.

CHAPTER FOUR

CASE STUDIES

Four types of structures have been selected within New South Wales to be field-tested. The structures that will be discussed are:

TABLE 14 TEST STRUCTURES

Building Type	Flooring	Structure	Concrete Strength	Ceiling system	Air Gap	Cornices	Insulation in ceiling
A	250mm reinforced concrete slab	Concrete slab & concrete block (single and double) load bearing walls	40mpa	2 layers standard 13mm plasterboard	150mm	Shadow line	no
B	270mm reinforced concrete slab with hardwood ceiling & joists	350mm x 350mm concrete and timber columns	40mpa	22mm hardwood flooring as the ceiling and 300mm x 75mm hardwood joists to underside of slabs	No	Square set	n/a
C	220mm reinforced concrete slab with polystyrene fill	350mm x 350mm concrete and timber columns	40mpa	22mm hardwood flooring as the ceiling and 300mm x 75mm hardwood joists to underside of slabs	No	Square set	n/a
D	Post tensioned concrete slab 180mm	150mm concrete load bearing walls	40mpa	250mm air gap with 13mm standard plasterboard on suspended ceiling system	150mm in living areas & 350mm in bathroom	Shadow line	no

CASE STUDY

Type A System

4.0 FLOOR CEILING SYSTEM – Type A

The acoustic performance of the floor / ceiling system **type A** was tested within a newly completed apartment and compared against existing laboratory results of a similar system.

Although the recently completed apartment was approved under the Building Code of Australia's Standards prior to the 2004 changes this study is comparing its performance against the current standard.

4.0.1 Type A System

250mm thick 40mPa concrete with 150mm air cavity and double layer 13mm plasterboard on a standard ceiling suspension system with shadowline corners.

The structure has load bearing concrete block double and single walls with 250mm reinforced concrete slabs.

Building: **A**

Date: 9th April, 2007 **Time**: between 10.15 am to 1.15 pm **Duration**: approx. 3 hours

Day Conditions: sunny with some cloud, no rain or wind. **Persons present no(s):** 4

Acoustic Engineers:

Stephen Gauld, BE (Mech), MIE Aust., MAAS Senior Acoustical Engineer MOB 0425350371

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Website: www.daydesign.com.au

Tapping Machine Bruel & Kjaer 3207 **Calibrated** 5th July, 2006

Sound Level Analyser Bruel & Kjaer 2260 Investigator **Calibrated** 12th October, 2006

1. Introduction

The building is located in NSW, and is a 250mm concrete slab with load bearing wall construction, two layers 13mm standard plasterboard ceiling (having shadowline wall ceiling junctions) on a suspended ceiling system.

The tests were conducted within the kitchen and dining room area of a penthouse apartment on the top floor (level 2 - source room) and within a bedroom located directly below (level 1 - receiving room).

The apartments were devoid of furniture. They were available just prior to handover.

2. Test Procedure

- Test methods for field measurement.
- 85kg male walker walked in a circular and figure 8 configuration, for duration of 90 seconds on all surfaces; tile, concrete and carpet (recorded for 60 seconds).
- Sound was recorded at maximum sound levels for 100 footsteps per 60 seconds. The sound recorder was hand held below the midpoint of the ceiling, underneath the walker.
- 60kg female walker with synthetic high heel shoes, walking in a circular configuration for duration of 90 seconds on tile (recorded for 60 seconds).
- 2.5kg Grip Ball dropped from 1000mm height in a random pattern on tile, concrete and carpet.
- Use of tapping machine used in accordance with the requirements of AS / NZS ISO 140-7:1998, MOD Part 7. Field measurements of impact sound insulation of floors), on all three surfaces (concrete, tile and one layer carpet).

3. Location(s) of Tapping Machine

Floor 2 penthouse apartment within the kitchen and dining area:

1. on kitchen tile;
2. on bare concrete floor; and
3. on one layer carpet (no underlay).

Information was recorded by the Bruel & Kjaer 2260 Investigator and further analysed by the Bruel & Kjaer Qualifier software program.

4. Structure Type

- 250mm concrete slab (no topping) with concrete block single and double load bearing walls.

- The height of the vertical space from top of slab to underside of slab above approximately 2650mm.

5. Description of Floor Ceiling System Construction

Plasterboard: Two layers of 13mm standard plasterboard, with a shadowline to the corner junction between ceiling and wall.

Ceiling System: The plasterboard ceiling is suspended from the slab with approximately 150mm cavity beneath the 250mm concrete.

Floor Surfaces: Tiling and proposed carpeted floor above (although at the time the carpets had not been laid).

Tiled area: The tile floor is a 4.5mm porcelain tile on a 4.55mm rubber acoustic pad, adhered to concrete.

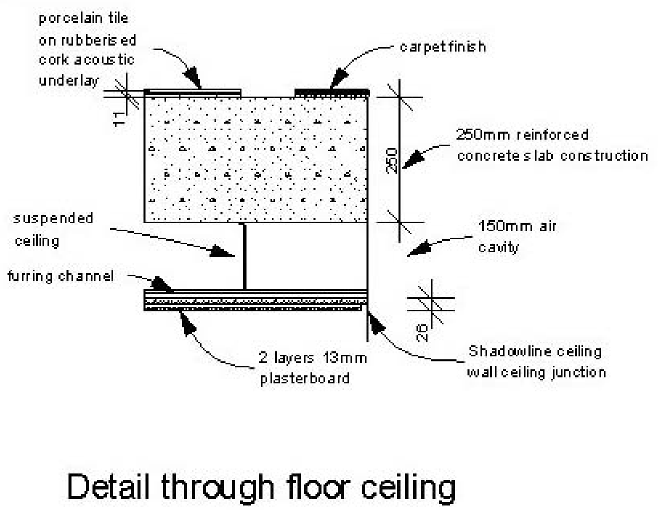

FIGURE 10 – TYPE A FLOOR / CEILING SYSTEM

6. Description of Source Room

Room: Penthouse Open plan living, dining, kitchen, entry

Floor: 2

Width of living/dining: 9000mm

Depth of living/dining: 6000mm

Height: 2500mm minimum (area had a vaulted ceiling unmeasured)

Volume: 55 m^3 minimum (not including vaulted ceiling area)

Floor Surface Area: 75 m^2

Internal Perimeter: 51 metres

Internal Wall Surface: 128 m^2 approx. (not including vaulted ceiling area)

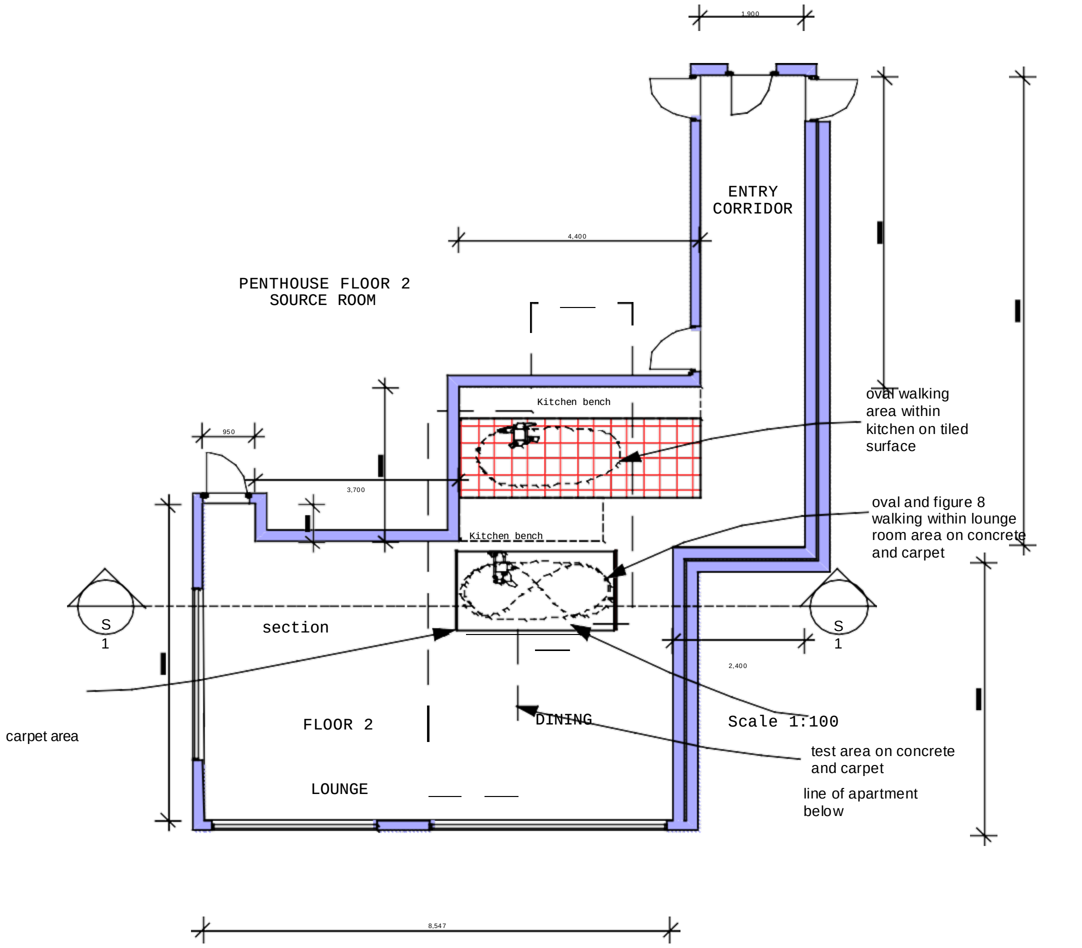

FIGURE 11 – FLOOR PLAN OF PENTHOUSE FLOOR 2

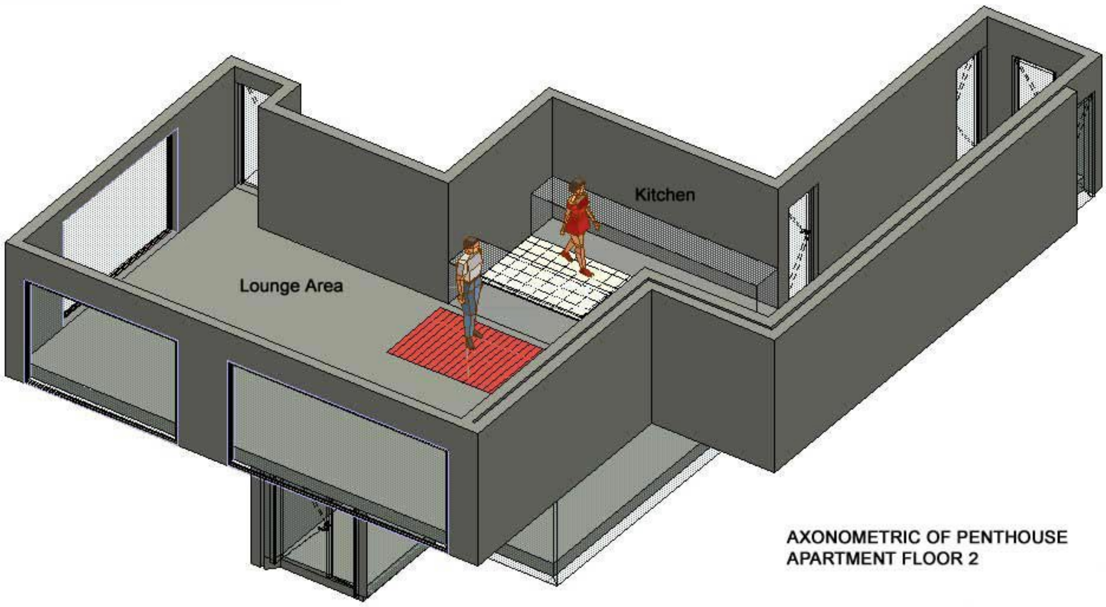

FIGURE 12 - AXONOMETRIC INDICATING PENTHOUSE FLOOR 2 (not to scale)

The female walker is walking within the tiled kitchen area. The male walker is walking on a piece of carpet provided within the dining area situated directly above the bedroom area below.

Surfaces:

- Tile floor in kitchen
- Plastered walls were paint finished
- Window and sliding door surfaces – glass
- Entry doors – hollow core
- Skirtings in place
- Electrical points and lighting complete
- Kitchen in place and finished
- Apartment devoid of, but ready for, carpet

DETAIL THROUGH FLOOR / CEILING SYSTEM

Indicates suspended ceiling with 2 layers 13mm plasterboard with shadowline corners at the wall / ceiling junction. The tests were conducted on concrete, carpet and tile.

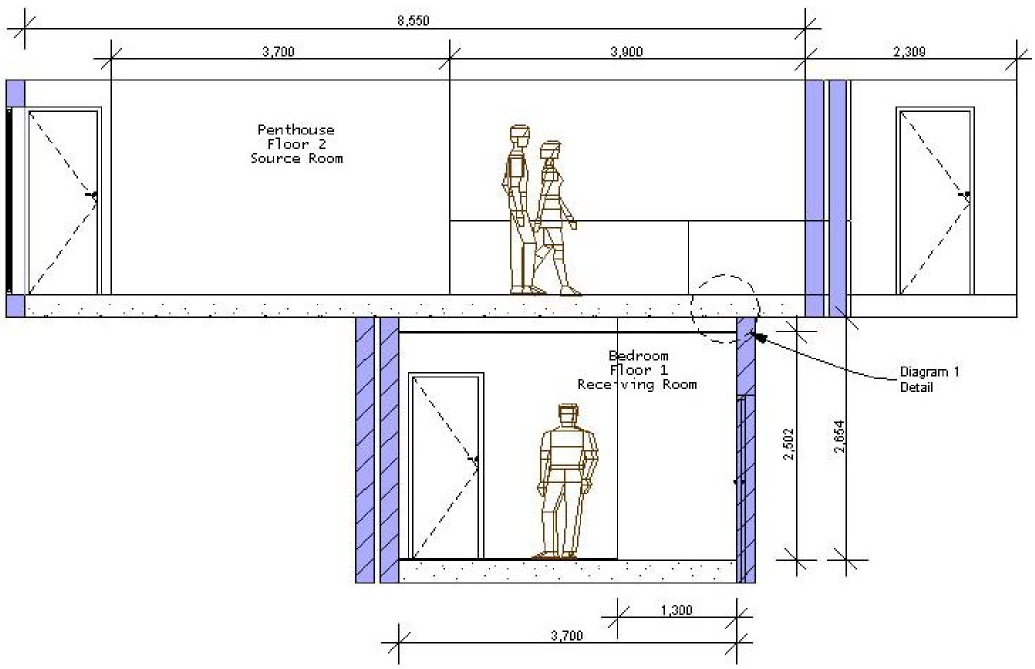

FIGURE 13 – CROSS SECTION THROUGH FLOORS 1 & 2

Indicates penthouse above and bedroom area below (not to scale).

7. Description of Receiving Room

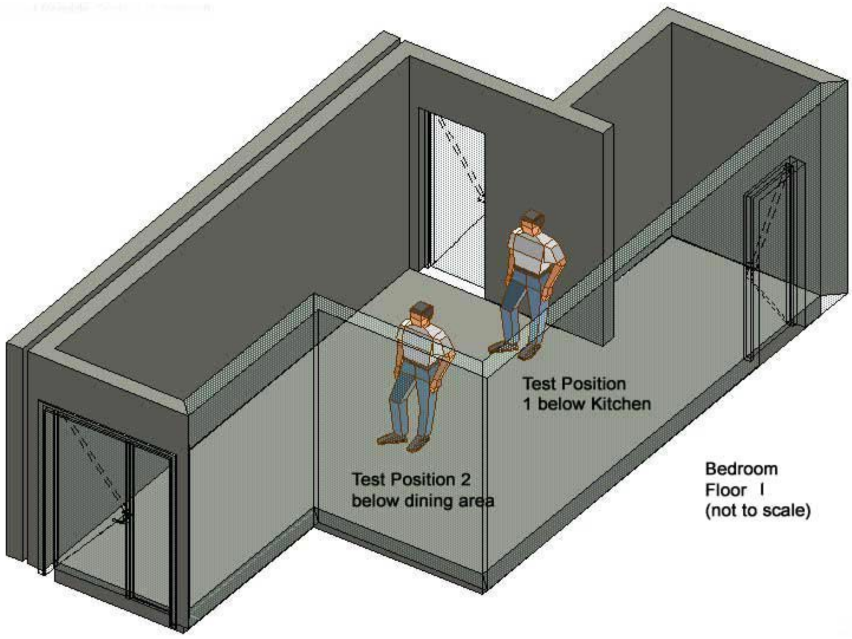

FIGURE 14 - AXONOMETRIC BEDROOM FLOOR 1 (not to scale)

Room: Bedroom

Floor: 1

Width: 3700mm

Depth: 8300mm

Height: 2500mm

Volume: 55 m^3

Floor Surface Area: 22 m^2

Internal Perimeter: 25 lineal metres

Internal Wall Surface: 63 m^2

Surfaces:

- Plastered walls were paint finished
- Window and sliding door surfaces – glass
- Bedroom and bathroom doors – hollow core
- Skirtings in place
- Electrical points and lighting complete
- Apartment devoid of but ready for carpet i.e. floors were bare concrete.

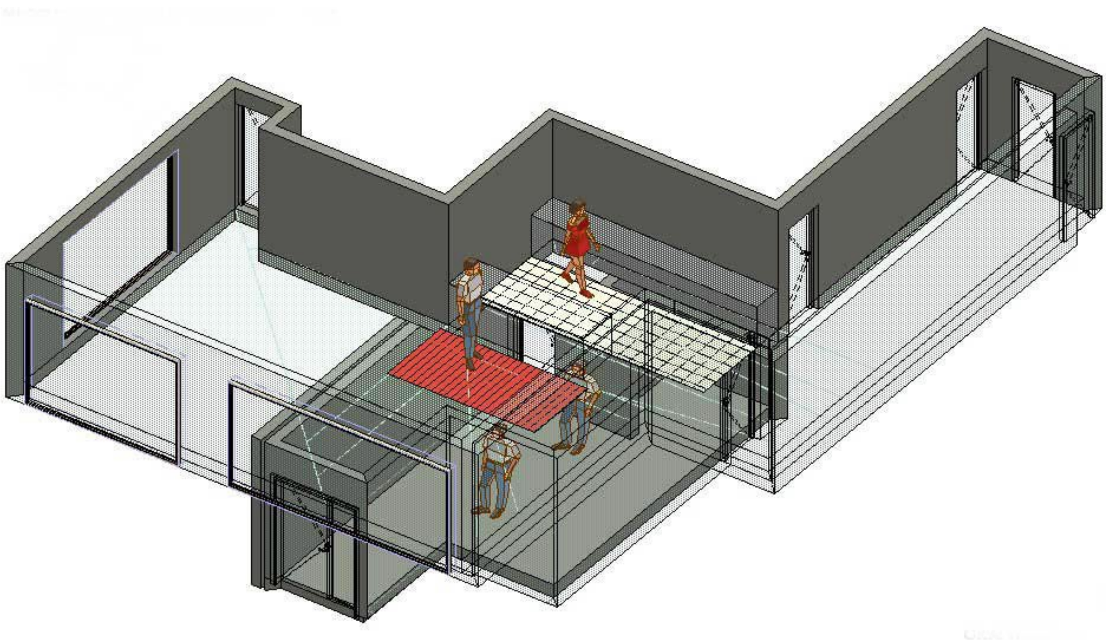

FIGURE 15 - AXONOMETRIC OF BOTH APARTMENTS (with transparent walls)

Diagram below indicates test positions within the receiving room (nts).

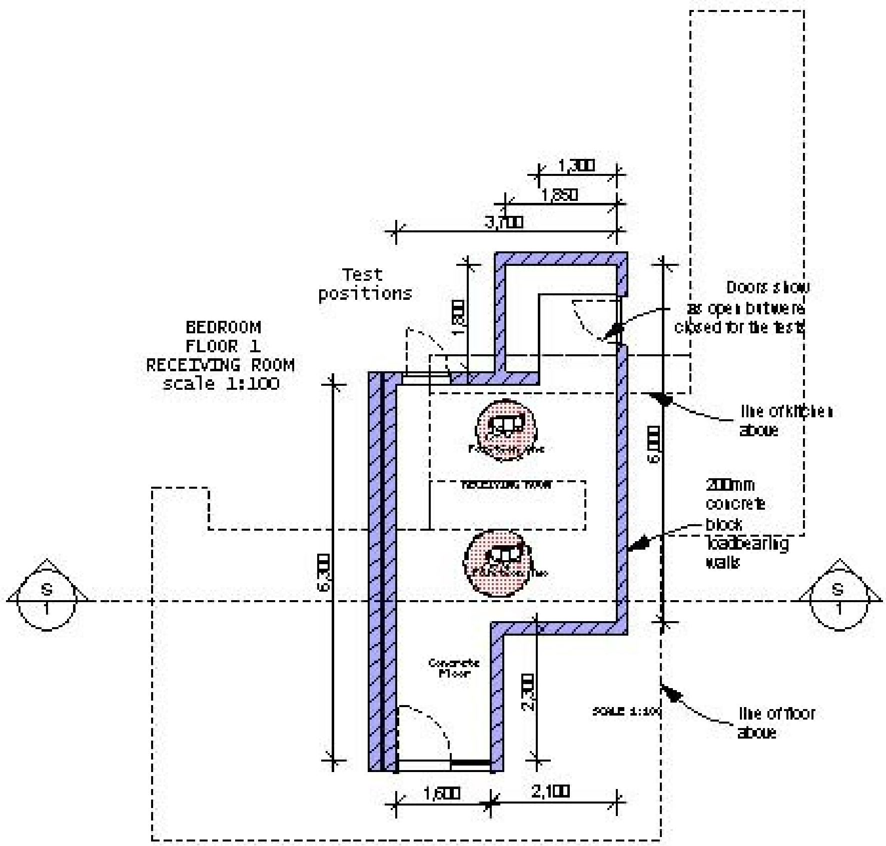

FIGURE 16 - FLOOR PLAN – BEDROOM FIRST FLOOR – RECEIVING ROOM

8. Background Noise Levels

We chose to test on Easter Monday 2007, which was a public holiday weekend, in order to reduce and/or minimise the background noise.

The ambient noise levels were recorded at 35 dBA.

9. Considerations

1. The testing was not without its faults. It was revealed that because the kitchen area was so small it was hazardous for the walkers to walk in a figure 8 at such a fast pace. It caused dizziness, so we had to have the walkers walk in an oval pattern within the kitchen area for a reduced duration of 90sec versus 180secs plus.

2. For safety reasons the acoustic engineer believed that he could capably record the impact within a 60 second duration rather than test for the entire 180 seconds.

3. Within the open lounge room area we were able to have the male walker walk in both the oval and figure 8 patterns alternatively.

4. We extended the walking tests to include a 60kg female walker with high heels, and when we listened with our audible ear in the receiving room, the sound was quite obvious. The higher ‘click clack’ of the high heels was more noticeable apparently, and the test results speak for themselves.

5. The tests revealed to the audible ear that the live walking on the carpet was pointless, as the carpet absorbed all impact sound.

6. We deliberately chose an apartment that had a kitchen above a bedroom. This was the only configuration of this type in the building.

7. We chose to only use the 2.5kg Grip Ball because, when we tested the 3.0kg hollow ball with the audible ear in comparison to the 2.5kg sand ball, the impact of the smaller more compact ball, we felt, would yield better results.

8. The project manager stated that we should possibly have had underlay under the carpet. But we quickly realised with the male walker that there was no audible sound being transferred. Perhaps there may have been a difference with the tapper and the 2.5kg ball.

9. It is not necessary to describe in full detail the aspects of the source room but I have, for the benefit of the reader.

TABLE 15 – ACOUSTIC TESTS CONDUCTED – DAY ONE – BUILDING SYSTEM A

TEST	BUILDING A	FLOOR SURFACE	TEST TYPE	DETAILS	DURATION
1	A	Tile with 4.5mm acoustic underlay	85kg male walker	Resin Sole Shoe walking in oval shape within restricted kitchen area	90secs walking but recorded for 60sec
2	A	Tile with 4.5mm acoustic underlay	85kg male walker	Resin Sole Shoe walking in oval shape within restricted kitchen area	90secs walking but recorded for 60sec
3	A	Tile with 4.5mm acoustic underlay	60kg female walker	Plastic sole High Heels	90secs walking but recorded for 60sec
4	A	Bare Concrete 250mm	80kg male walker	Resin Sole Shoe	90secs walking but recorded for 60sec
5	A	Carpet - no underlay	80kg male walker	Resin Sole Shoe	90secs walking but recorded for 60sec
6	A	Tile with 4.5mm acoustic underlay	2.5kg rubber Grip Ball	110mm ball dropped from 1000mm high	90secs duration but recorded for 60sec
7	A	Bare Concrete 250mm	2.5kg rubber Grip Ball	110mm ball dropped from 1000mm high	90secs duration but recorded for 60sec
8	A	Carpet - no underlay	2.5kg rubber Grip Ball	110mm ball dropped from 1000mm high	90secs duration but recorded for 60sec
9	A	Bare Concrete 250mm	Tapping Machine	Bruel & Kjaer 3207	180sec
10	A	Bare Concrete 250mm	Tapping Machine	Bruel & Kjaer 3207	180sec
11	A	Bare Concrete 250mm	Tapping Machine	Bruel & Kjaer 3207	180sec
12	A	Bare Concrete	Tapping	Bruel & Kjaer	180sec

		250mm	Machine	3207	
13	A	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
14	A	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
15	A	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
16	A	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
17	A	Tile with 4.5mm acoustic underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
18	A	Tile with 4.5mm acoustic underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
19	A	Tile with 4.5mm acoustic underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
20	A	Tile with 4.5mm acoustic underlay	Tapping Machine	Bruel & Kjaer 3207	180sec

CASE STUDY

Type B System

4.2 FLOOR CEILING SYSTEM

The acoustic performance of the floor / ceiling system **type B** was conducted within an apartment nearing completion apartment. According to Rex Broadbent of the CSIRO, the system was unable to be replicated in the laboratory as the crane is incapable of carrying the weight of a 270 thick slab with dimensions of 3.6m x 3.2m.

4.2.1 **Type B System**

270mm thick (40mpa concrete on an existing 22mm thick hardwood floor (serving as the ceiling system in the floor below) on 300mm x 75mm hardwood joists. Supported by 400mm x 250mm hardwood bearer and 250mm x 250mm hardwood post.

Type B System

Building: **B**

Date: 9th April, 2007 **Time**: between 2.30 am to 5.30 pm **Duration**: approx. 3 hours

Day Conditions: sunny with some cloud, no rain or wind. **Persons present no(s):** 2

Acoustic Engineers:

Stephen Gauld, BE (Mech), MIE Aust., MAAS Senior Acoustical Engineer

MOB 0425350371

William Wang, BE (Mechatronics), Technical Officer MOB 0425 388 906

Acoustic Company: Day Design Acoustic Consultants Pty Ltd

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Phone: (02) 9584 2639 **Fax:** (02) 9584 2619

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Website: www.daydesign.com.au

Tapping Machine Bruel & Kjaer 3207 **Calibrated** 5th July, 2006

Sound Level Analyser Bruel & Kjaer 2260 Investigator **Calibrated** 12th October, 2006

Software Program Bruel & Kjaer Qualifier

1. Introduction

The building is located in Newcastle, and for this particular test, the thickness of the concrete in this area is 270mm.

In one area of the lounge room (closer to the windows) the concrete was believed to have been 270mm thick to counter balance the canterlevering balcony.

Underneath the concrete is an existing hardwood floor of 25mm atop 300mm x 75mm hardwood joists.

This existing hardwood system formed an exposed ceiling (as this part of the building was a refurbishment).

Both the source and receiving rooms are identical to each other.

The tests were conducted within the kitchen and open plan lounge/dining areas.

The apartment was devoid of furniture, and at the time, nearing completion.

2. Test Procedure

Test methods for field measurement.

1. Sound was recorded at maximum sound levels for 100 footsteps per 60 seconds. The sound recorder was hand held below the midpoint of the ceiling, underneath the walker.
2. 60kg female walker with synthetic high heel shoes, walking in a circular configuration for duration of 90 sec.
3. 2.5kg Grip Ball dropped from 1000mm height in a random pattern.
4. Use of tapping machine used in accordance with the requirements of AS / NZS ISO 140-7:1998, MOD). Field measurements of impact sound insulation of floors), on all three surfaces (tile, concrete and one layer carpet).

3. Location(s) of Tapping Machine and Position(s) of Walker(s) – Source Room

Floor 2:

1. on bare concrete floor; and
2. on one layer carpet (no underlay).

Information was recorded by the Bruel & Kjaer 2260 Investigator and further analysed by Bruel & Kjaer Qualifier software program:

4. Structure Type

270mm thick 40 mpa concrete slab (no topping) with hardwood bearers and columns. The height of the vertical space from top of slab to underside of the hardwood joists above approximately 3300mm.

5. Description of Floor Ceiling System Construction

The concrete thickness was 270mm so that the balcony through the french doors could cantilever. The bare concrete area is intended to have carpet although in an adjoining apartment, polished concrete has been proposed. At the time the carpets had not been laid. No acoustic material was provided.

Ceiling System: The hardwood floor formed the formwork for the concrete floor above to become the ceiling for the apartment below.

Floor Surfaces: Proposed carpeted floor above (although at the time the carpets had not been laid and an adjoining apartment has polished concrete proposed.

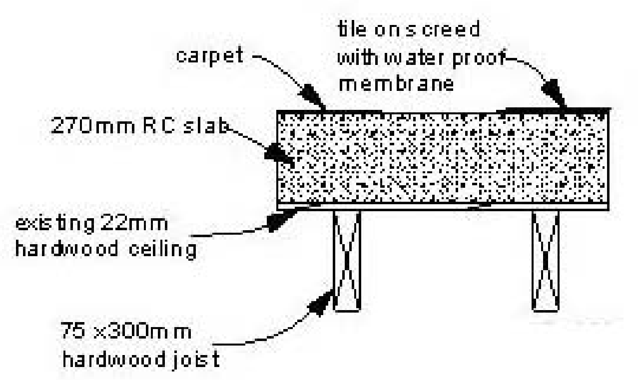

FIGURE 17 – FLOOR / CEILING DETAIL SYSTEM 270mm

6. Description of Source Room

Room: Open plan lounge dining

Floor: 2

Width: 8060 mm

Depth: 7340 mm

Height: 3200 mm (to underside of 300mm joists)

Volume: 227 m^3

Floor Surface Area: 71 m^2 (includes open study & corridor areas)

Internal Perimeter: 42 lineal metres

Internal Wall Surface: 135 m^2

Surfaces: Painted plaster, sliding sash windows and timber & glass french doors and hollow core interior door surfaces - glass, skirtings in place, wiring eg. electrical points, lighting and kitchen areas almost complete. The apartment was ready for carpet.

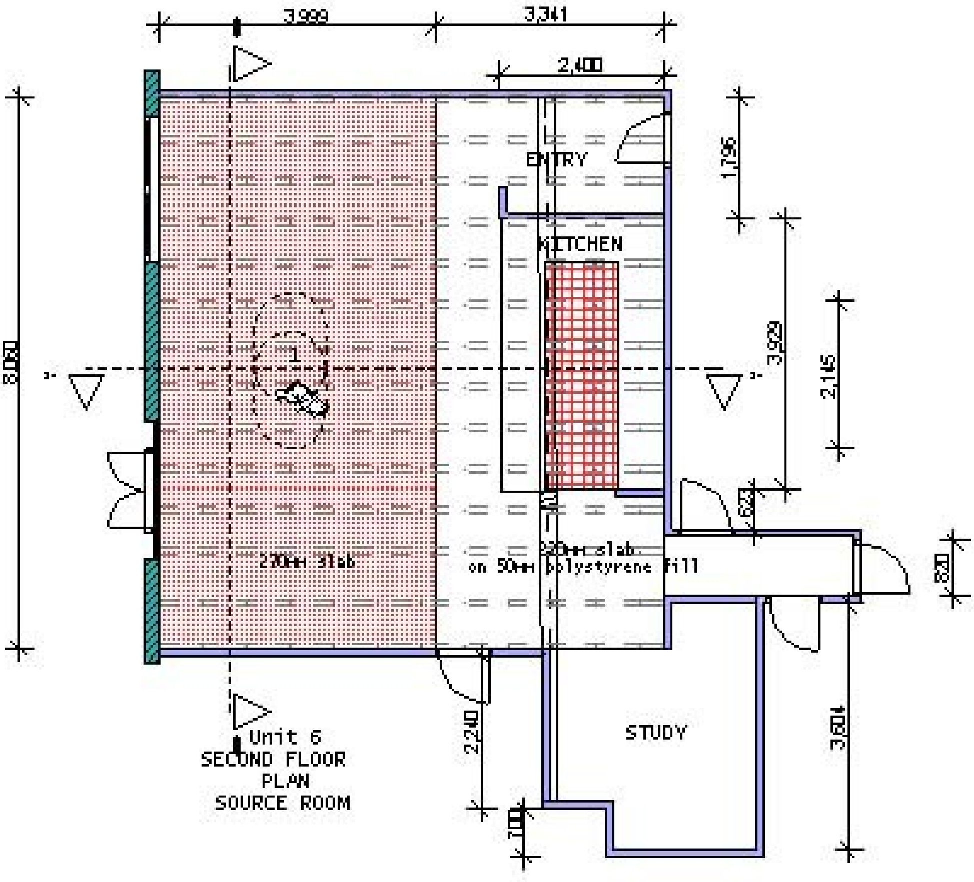

FIGURE 18 – FLOOR PLAN SOURCE ROOM (not to scale)

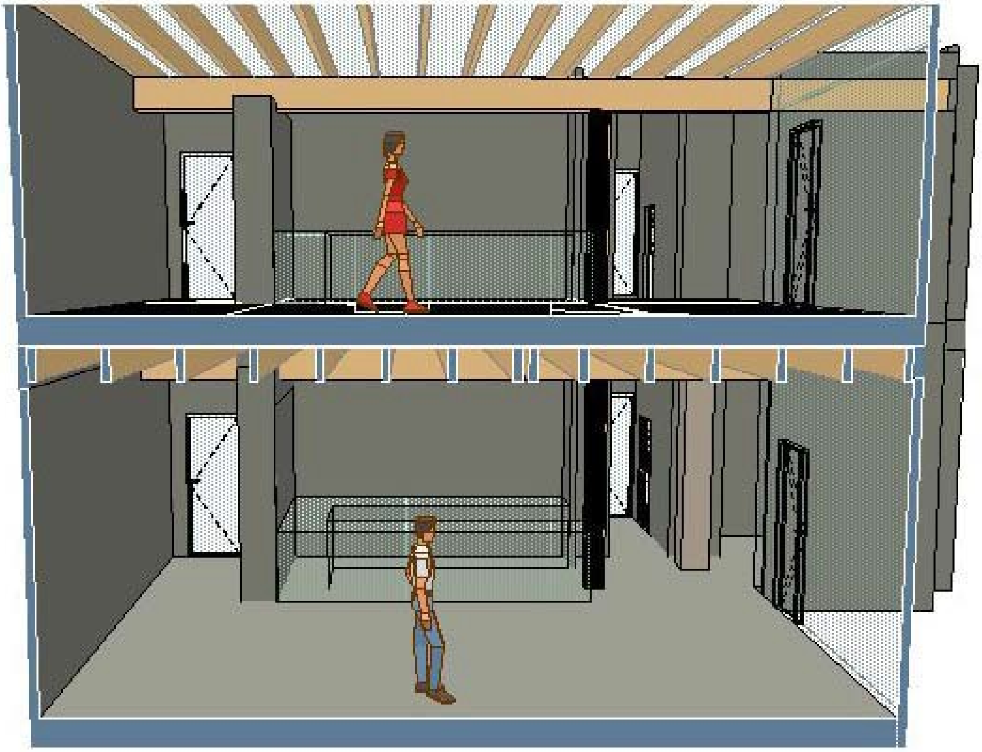

FIGURE 19 - CUTAWAY OF BOTH SOURCE & RECEIVING ROOMS (nts)

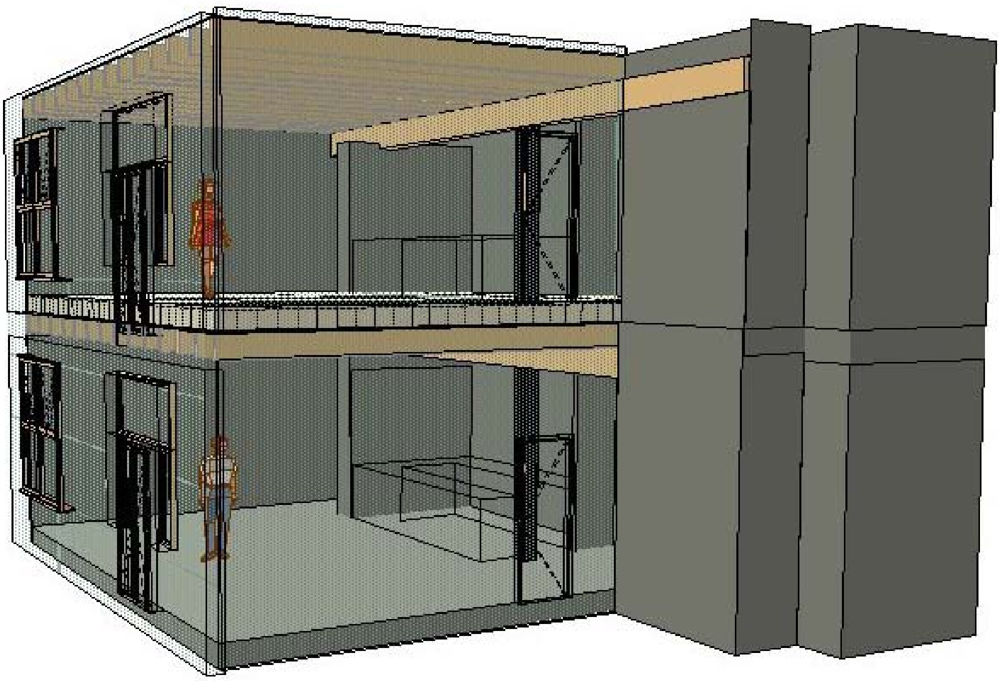

FIGURE 20 – AXONOMETRIC OF SOURCE & RECEIVING ROOMS (nts)

7. Description of Receiving Room

Room: Open plan lounge dining

Floor: 1

Width: 8060 mm

Depth: 7340 mm

Height: 3200 mm (to underside of 300mm joists)

Volume: 227 m^3

Floor Surface Area: 71 m^2 (includes open study & corridor areas)

Internal Perimeter: 42 lineal metres

Internal Wall Surface: 135 m^2

Surfaces: Tiled floor, painted plaster, window and sliding door surfaces - glass, skirtings in place, wiring eg. electrical points, lighting and kitchen areas in complete. The apartment was ready for carpet.

Test positions:

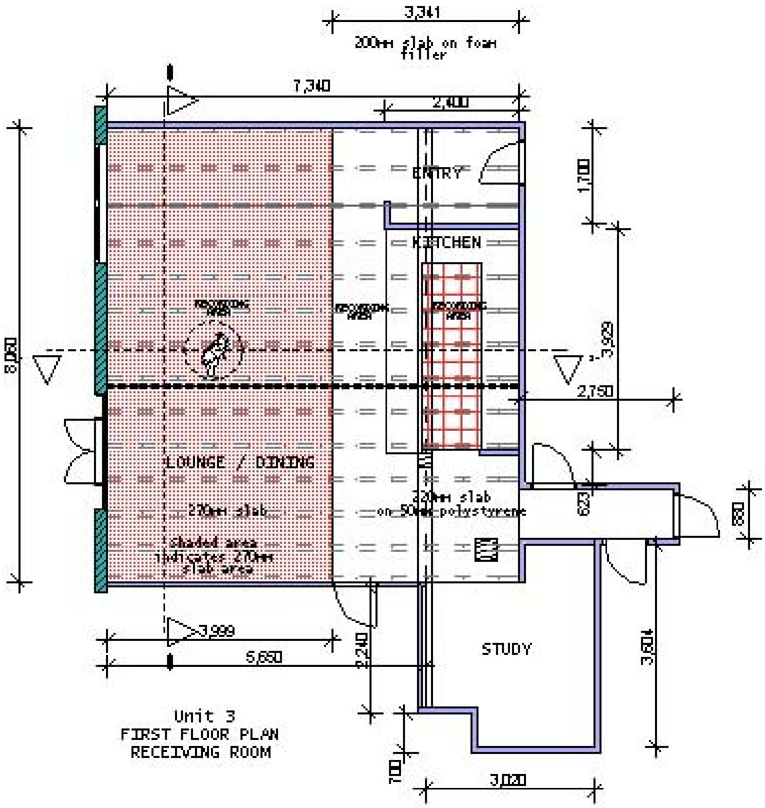

FIGURE 21 – FLOOR PLAN - RECEIVING ROOM

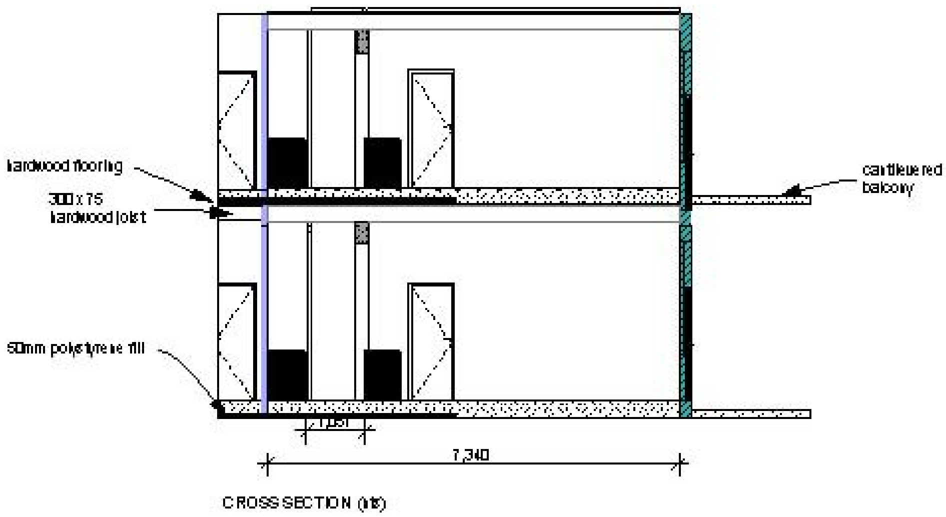

FIGURE 22 - CROSS SECTION THROUGH STRUCTURE

8. Background Noise Levels

We chose to test on Easter Monday, which was a public holiday weekend, in order to reduce and/or minimise the impact of background noise.

The ambient noise levels were recorded.

9. Considerations

The testing revealed that, because the kitchen area was so small, it was a safety hazard for the walker to walk in a figure 8 at such a fast pace. It caused dizziness, so we were forced to have the walker walk in an oval pattern for a reduced duration of 90 seconds instead of the required 180 seconds and they were recorded for a 60 second duration. We were then forced to replicate the time frame within the other areas.

The acoustic technician believed that he could capably record the impact sound within the 60 second duration.

We extended the walking tests to include a 60kg female walker with high heels, and when we listened with our audible ear in the receiving room, the sound was quite obvious. The higher ‘click clack’ of the high heels was more noticeable apparently, and the test results speak for themselves.

The tests revealed that the live walker on the carpet was pointless, as the carpet absorbed all impact sound. Even though the walker was a heavy walker, the technician pointed out on the day that he could not audibly hear anything and therefore he believed that the sound level meter would have only picked up the ambient noise levels outside the room.

We chose these apartments because of the hardwood ceiling system that set these ceiling floor systems apart.

We chose to only use the 2.5kg Grip Ball, because we felt that when we tested the 2.0kg hollow ball in comparison to the 2.5kg sand ball, the impact of the smaller heavier ball would yield better results.

TABLE 16 – ACOUSTIC TESTS CONDUCTED – DAY ONE – BUILDING SYSTEM B

TEST	System B	FLOOR SURFACE	TEST TYPE	DETAILS	DURATION
1	B	Bare concrete 270mm on top of both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
2	B	Bare concrete 270mm on top of both hardwood flooring 22mm and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
3	B	Bare concrete 270mm on top of both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
4	B	Bare concrete 270mm on top of both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
5	B	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
6	B	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
7	B	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
8	B	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
9	B	Concrete	2.5kg rubber Grip Ball	Bruel & Kjaer 3207	90secs duration but recorded for 60sec
10	B	Tile adhered to concrete	60kg female walker	Bruel & Kjaer 3207	90secs walking but recorded for 60sec

CASE STUDY

Type C System

4.3 FLOOR CEILING SYSTEM

The acoustic performance of the floor / ceiling system **type C** was conducted within an apartment nearing completion apartment. According to Rex Broadbent of the CSIRO, the system was unable to be replicated in the laboratory as the crane is incapable of carrying the weight of a 220 thick slab with dimensions of 3.6m x 3.2m.

Type C System

220mm thick 40mpa concrete with 50mm polystyrene, above existing 22mm thick hardwood floor (serving as the ceiling system in the floor below) on 300mm x 75mm hardwood joists. Supported by 400mm x 250mm hardwood bearer and 250mm x 250mm hardwood post and discontinuous and single stud walls.

Type C System

Building: **C**

Date: 9th April, 2007 **Time**: between 2.30 am to 5.30 pm **Duration**: approx. 3 hours

Day Conditions: sunny with some cloud, no rain or wind. **Persons present no(s):** 2

Acoustic Engineers:

Stephen Gauld, BE (Mech), MIE Aust., MAAS Senior Acoustical Engineer

MOB 0425350371

William Wang, BE (Mechatronics), Technical Officer MOB 0425 388 906

Acoustic Company: Day Design Acoustic Consultants Pty Ltd

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Website: www.daydesign.com.au

Tapping Machine Bruel & Kjaer 3207 **Calibrated** 5th July, 2006

Sound Level Analyser Bruel & Kjaer 2260 Investigator **Calibrated** 12th October, 2006

Software Program Bruel & Kjaer Qualifier

1. Introduction

The building is located in Newcastle, and for this particular test, the thickness of the concrete is 220mm on 50mm polystyrene fill.

Underneath the concrete is an existing hardwood floor of 22mm atop 300mm x 75mm hardwood joists.

This existing hardwood system formed an exposed ceiling (as this part of the building was a refurbishment).

Both the source and receiving rooms are identical to each other.

The tests were conducted within the kitchen and open plan lounge/dining areas.

The apartment was devoid of furniture, and at the time, nearing completion.

2. Test Procedure

Test methods for field measurement.

1. Sound was recorded at maximum sound levels for 100 footsteps per 60 seconds. The sound recorder was hand held below the midpoint of the ceiling, underneath the walker.
2. 60kg female walker with synthetic high heel shoes, walking in a circular configuration for duration of 90 sec.
3. 2.5kg Grip Ball dropped from 1000mm height in a random pattern.
4. Use of tapping machine used in accordance with the requirements of AS / NZS ISO 140-7:1998, MOD). Field measurements of impact sound insulation of floors), on all three surfaces (tile, concrete and one layer carpet).

3. Location(s) of Tapping Machine and Position(s) of Walker(s) – Source Room

Floor 2:

1. on kitchen tile;
2. on bare concrete floor; and
3. on one layer carpet (no underlay).

Information was recorded by the Bruel & Kjaer 2260 Investigator and further analysed by Bruel & Kjaer Qualifier software program:

4. Structure Type

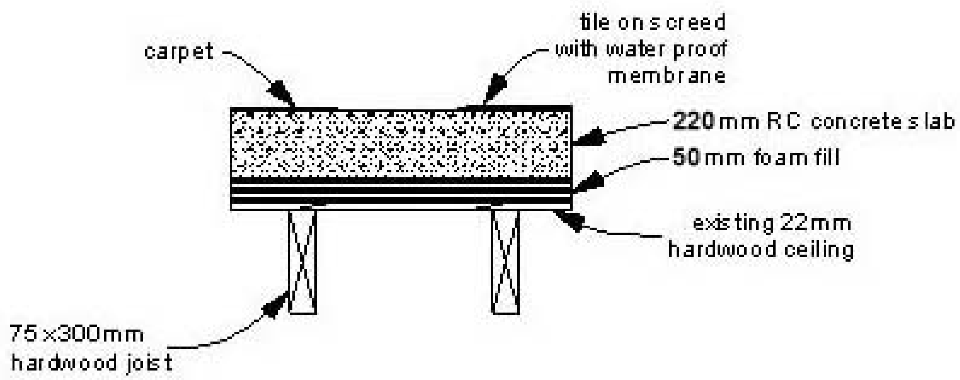
220mm thick 40mpa concrete slab (no topping) on 50mm polystyrene fill with hardwood bearers and columns. The height of the vertical space from top of slab to underside of the hardwood joists above is approximately 3300mm.

5. Description of Floor Ceiling System Construction

The concrete thickness was 220mm and the bare concrete area has carpet proposed. At the time the carpets had not been laid. The tile floor was a 4.5mm tile adhered to the membrane set to concrete. No acoustic material was provided.

Ceiling System:	The hardwood floor formed the formwork for the concrete floor above to become the ceiling for the apartment below.
Floor Surfaces:	Tiling and proposed carpeted floor above (although at the time the carpets had not been laid).
Tiled area:	The tile floor is a 4.5mm tile on a 4.55mm screed bed and water-proof membrane to concrete slab. No acoustic material was laid.

FIGURE 23 – FLOOR / CEILING DETAIL SYSTEMS 220mm



6. Description of Source Room

Room:	Open plan lounge dining
Floor:	2
Width:	8060 mm
Depth:	7340 mm
Height:	3200 mm (to underside of 300mm joists)
Volume:	227 m^3
Floor Surface Area:	71 m^2 (includes open study & corridor areas)

Internal Perimeter: 42 lineal metres

Internal Wall Surface: 135 m^2

Surfaces: Tiled floor, painted plaster, window and sliding door surfaces - glass, skirtings in place, wiring eg. electrical points, lighting and kitchen areas incomplete. The apartment was ready for carpet.

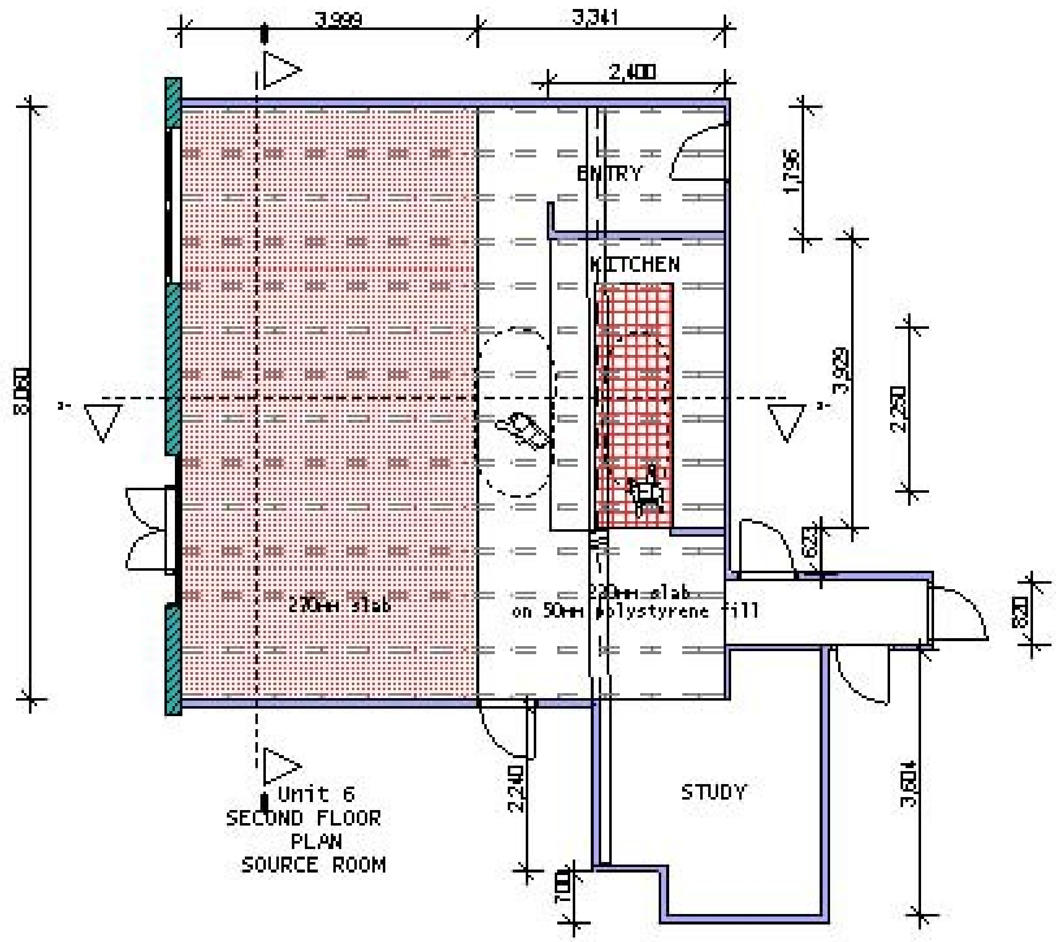


FIGURE 24 – FLOOR PLAN SOURCE ROOM (not to scale)

FIGURE 25 - CUTAWAY OF BOTH SOURCE & RECEIVING ROOMS (nts)

FIGURE 26 – AXONOMETRIC OF SOURCE & RECEIVING ROOMS (nts)

7. Description of Receiving Room

Room: Open plan lounge dining

Floor: 1

Width: 8060 mm

Depth: 7340 mm

Height: 3200 mm (to underside of 300mm joists)

Volume: 227 m^3

Floor Surface Area: 71 m^2 (includes open study & corridor areas)

Internal Perimeter: 42 lineal metres

Internal Wall Surface: 135 m^2

Surfaces: Tiled floor, painted plaster, window and sliding door surfaces - glass, skirtings in place, wiring eg. electrical points, lighting and kitchen areas incomplete. The apartment was ready for carpet.

Test positions:

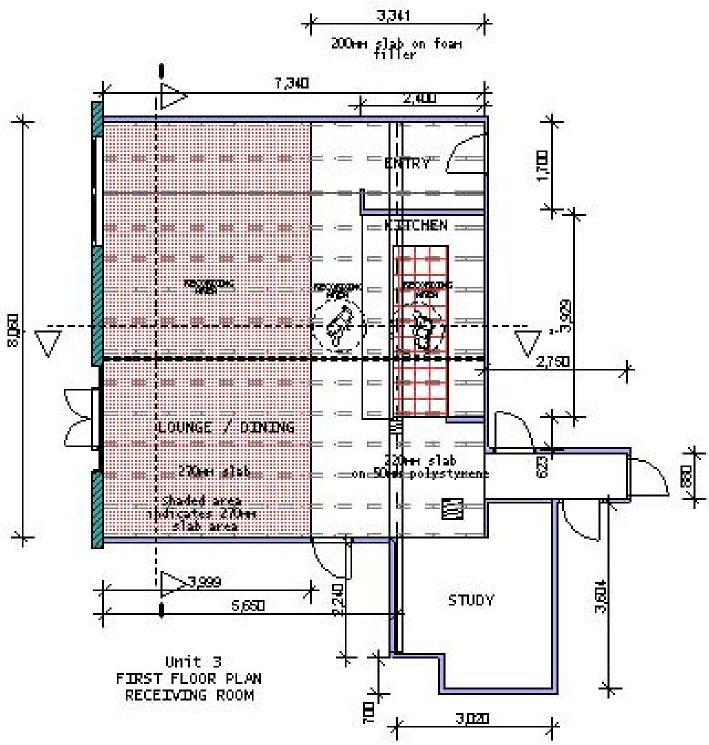


FIGURE 27 – FLOOR PLAN - RECEIVING ROOM

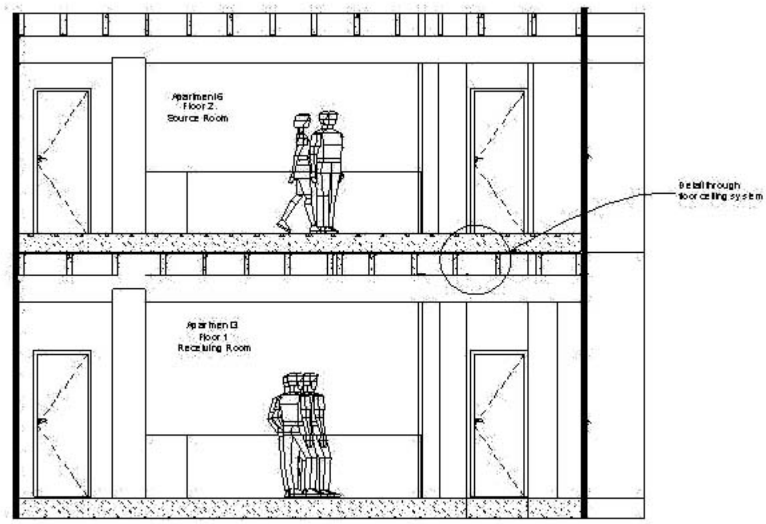


FIGURE 28 - CROSS SECTION THROUGH STRUCTURE

8. Background Noise Levels

We chose to test on Easter Monday, which was a public holiday weekend, in order to reduce and/or minimise the background noise. The ambient noise levels were recorded at 38 dBA.

9. Considerations

The testing revealed that, because the kitchen area was so small, it was a safety hazard for the walker to walk in a figure 8 at such a fast pace. It caused dizziness, so we were forced to have the walker walk in an oval pattern for a reduced duration of 90 seconds instead of the required 180 seconds and they were recorded for a 60 second duration. We were then forced to replicate the time frame within the other areas.

The acoustic technician believed that he could capably record the impact sound within the 60 second duration.

We extended the walking tests to include a 60kg female walker with high heels, and when we listened with our audible ear in the receiving room, the sound was quite obvious. The higher ‘click clack’ of the high heels was more noticeable apparently, and the test results speak for themselves.

The tests revealed that the live walker on the carpet was pointless, as the carpet absorbed all impact sound. Even though the walker was a heavy walker, the technician pointed out on the day that he could not audibly hear anything and therefore he believed that the sound level meter would have only picked up the ambient noise levels outside the room.

We chose these apartments because of the hardwood ceiling system that set these ceiling floor systems apart.

We chose to only use the 2.5kg Grip Ball, because we felt that when we tested the 2.0kg hollow ball in comparison to the 2.5kg solid sand ball, the impact of the smaller more compact ball would yield better results.

TABLE 17 – ACOUSTIC TESTS CONDUCTED – DAY ONE – BUILDING SYSTEM C

TEST	System C	FLOOR SURFACE	TEST TYPE	DETAILS	DURATION
1	C	Bare concrete 220mm thick on 50mm polystyrene fill on both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
2	C	Bare concrete 220mm thick on 50mm polystyrene fill on both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
3	C	Bare concrete 220mm thick on 50mm polystyrene fill on both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
4	C	Bare concrete 220mm thick on polystyrene fill on both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
5	C	Tile adhered to 220mm thick concrete on 50mm polystyrene fill on both hardwood floor and joists	Tapping Machine	Bruel & Kjaer 3207	180sec
6	C	Tile adhered to concrete	Tapping Machine	Bruel & Kjaer 3207	180sec
7	C	Tile adhered to concrete	Tapping Machine	Bruel & Kjaer 3207	180sec
8	C	Tile adhered to concrete	Tapping Machine	Bruel & Kjaer 3207	180sec

9	C	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
10	C	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
11	C	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
12	C	Carpet - no underlay	Tapping Machine	Bruel & Kjaer 3207	180sec
13	C	Concrete	2.5kg rubber Grip Ball	Bruel & Kjaer 3207	90secs duration but recorded for 60sec
14	C	Tile adhered to concrete	2.5kg rubber Grip Ball	Bruel & Kjaer 3207	90secs duration but recorded for 60sec
15	C	Carpet	2.5kg rubber Grip Ball	Bruel & Kjaer 3207	90secs duration but recorded for 60sec
16	C	Tile adhered to concrete	60kg female walker	Bruel & Kjaer 3207	90secs walking but recorded for 60sec

CASE STUDY

Type D System

4.4 FLOOR CEILING SYSTEM

The acoustic performance of the floor / ceiling system **type D** was conducted within a newly completed apartment and compared against laboratory results of similar system.

Type D System

180mm thick 40mpa post tensioned concrete with 150mm concrete loadbearing concrete walls. The area that was tested had one layer of 13mm standard plasterboard with shadowline corners to the ceiling wall junction. No insulation in the ceiling with varied ceiling cavities of 150 & 350mm. The timber flooring system was an Acousta Batten (insulation between) with19mm Blue gum timber floor, and the bathroom areas had a porcelain tile on screed with waterproofing.

REPORT PROFORMA – Type D System

Building: **D**

Date: 24th April, 2007 **Time**: between 3.30 pm to 5.30 pm **Duration**: approx. 3 hours

Day Conditions: overcast finished rain. **Persons present no(s):** 3

Acoustic Engineers:

Stephen Gauld, BE (Mech), MIE Aust., MAAS Senior Acoustical Engineer MOB 0425350371

William Wang, BE (Mechatronics), Technical Officer MOB 0425 388 906

Acoustic Company: Day Design Acoustic Consultants Pty Ltd

Address: Suite 17, 808 Forest Road, Peakhurst, Sydney, NSW 2210, Australia

Phone: (02) 9584 2639 **Fax:** (02) 9584 2619

Email: acoustics@daydesign.com.au

Website: www.daydesign.com.au

Tapping Machine Bruel & Kjaer 3207 **Calibrated** 5th July, 2006

Sound Level Analyser Bruel & Kjaer 2260 Investigator **Calibrated** 12th October, 2006

Software Program Bruel & Kjaer Qualifier

1. Introduction

The building is located in NSW, and is a 180mm post tensioned concrete slab with load bearing 150mm concrete wall construction, one layer 13mm standard plasterboard ceiling (having shadowline wall ceiling junctions) on a suspended ceiling system.

The tests were conducted within the lounge and dining room area source room through to lounge area (receiving) below as well as within bathroom to bathroom areas.

The apartments were devoid of furniture. They were nearing completion.

2. Test Procedure

Test methods for field measurement.

1. Sound was recorded at maximum sound levels for 100 footsteps per 60 seconds. The sound recorder was hand held below the midpoint of the ceiling, beneath the walker.
2. 85kg male walker with leather soled shoes, walking in a circular and figure "8" configuration for duration of 90 seconds but recorded for 60 seconds.
3. 60kg female walker with synthetic high heel shoes, walking in a circular configuration for duration of 90 seconds but recorded for 60 seconds.
4. 2.5kg Grip Ball dropped from 1000mm height in a random pattern.
5. Use of tapping machine used in accordance with the requirements of AS / NZS ISO 140-7:1998, MOD). Field measurements of impact sound insulation of floors), on all three surfaces (tile, concrete and one layer carpet).

3. Location(s) of Tapping Machine and Position(s) of Walker(s) – Source Room

Floor 2:

1. on timber flooring - Acousta Batten with 19mm blue gum flooring; and
2. on porcelain tile.

Information was recorded by the Bruel & Kjaer 2260 Investigator and further analysed by Bruel & Kjaer Qualifier software program.

4. Structure Type

180mm thick 40 mpa post tensioned concrete slab (no topping) 150mm load-bearing concrete walls.

The height of the vertical space from top of slab to underside of the plasterboard above varies in the lounge 2600mm to 2400mm in the bathroom (tile to plasterboard).

5. Description of Floor Ceiling System Construction – Acousta Batten

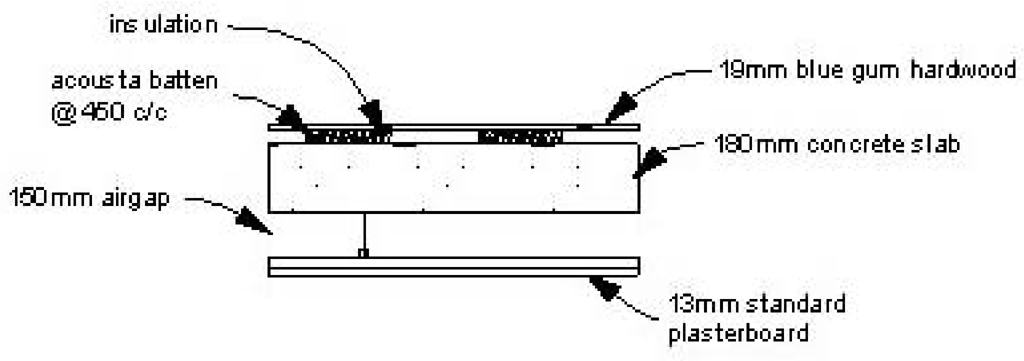


FIGURE 29 – FLOOR DETAIL - TYPE D SYSTEM

6. Description of Source Room(s)

Room area 1	Open plan lounge dining area
Floor:	3
Width:	5463 mm
Depth:	8983 mm
Height:	2600 mm (from FFL to underside of ceiling)
Volume:	224 m^3
Floor Surface Area:	86 m^2
Internal Perimeter:	46 lineal metres
Internal Wall Surface:	120 m^2

Surfaces:

- Acousta batten timber floor on 180mm concrete slab
- painted plaster
- window and sliding door surfaces - glass
- electrical points, lighting in ceiling complete

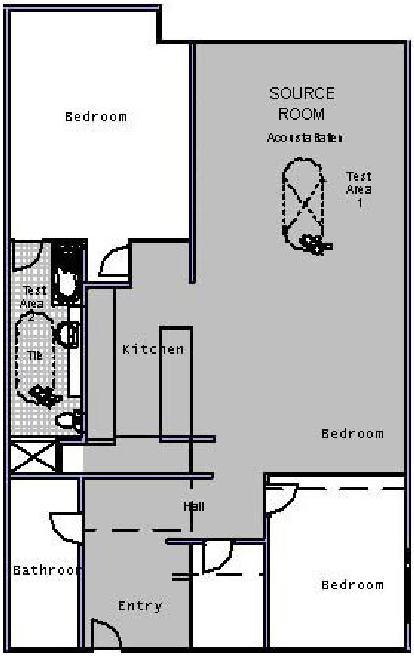


FIGURE 30 – FLOOR PLAN – SOURCE ROOM

Room area 2	**Bathroom Area**
Floor:	3
Width bathroom:	1885 mm
Depth:	4683 mm
Height:	2400 mm
Volume:	21 m^3
Floor Surface Area:	8.8 m^2
Internal Perimeter:	13 lineal metres
Internal Wall Surface:	31.5 m^2

Surfaces:

- tiled floor with screed and membrane only on 180mm concrete slab
- painted plaster
- electrical points, lighting in ceiling complete

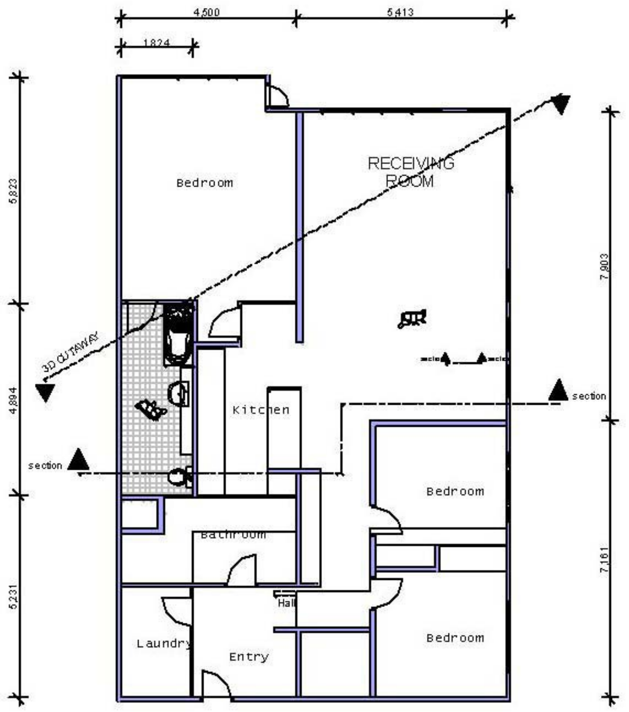


FIGURE 31 – FLOOR PLAN – RECEIVING ROOM

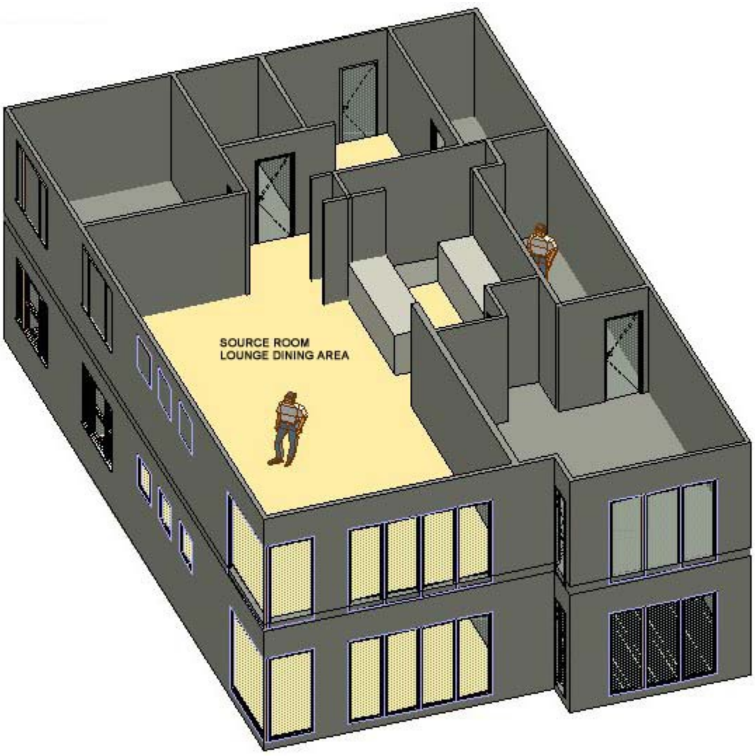


FIGURE 32 – AXONOMETRIC OF SOURCE & RECEIVING ROOMS

7. Description of Receiving Room

<u>Room Area 1</u>	Open plan lounge dining
Floor:	2
Width (lounge):	5413 mm
Depth (lounge):	7558 mm
Height:	2600 mm
Volume:	179 m^3
Floor Surface Area:	69 m^2
Internal Perimeter:	54 lineal metres
Internal Wall Surface:	140 m^2

Surfaces:

- timber floor
- painted plaster
- window and sliding door surfaces – glass, skirtings in place
- electrical points, lighting and kitchen areas incomplete

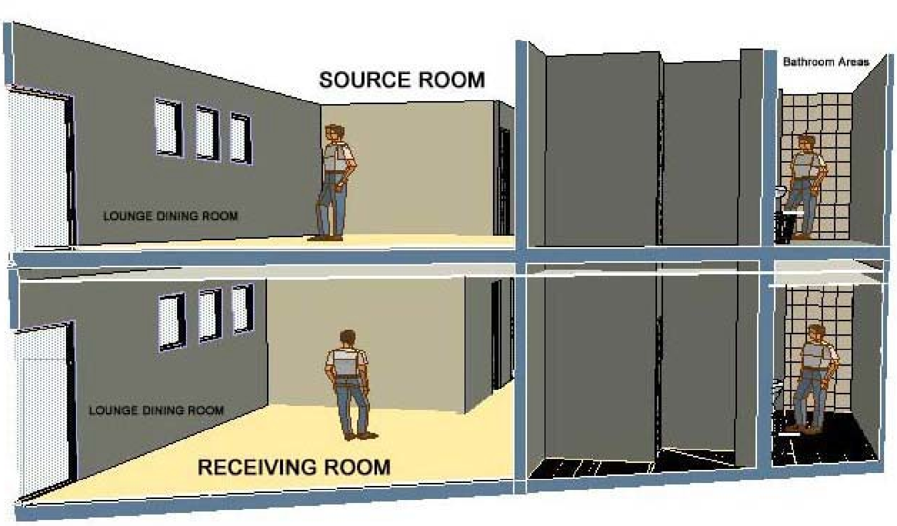


FIGURE 33 – CUTAWAY OF BOTH RECEIVING AND SOURCE ROOMS

<u>Room Area 2</u> Bathroom Area

Floor: 2

Width: 1824 mm

Depth: 5123 mm

Height: 2400 mm

Volume: 24 m^3

Floor Surface Area: 10 m^2

Internal Perimeter: 15 lineal metres

Internal Wall Surface: 36 m^2

Surfaces:

- tiled floor with screed and membrane (no acoustic barrier)
- painted plaster & tile walls
- glass shower door
- painted timber door – hollow core

FIGURE 34 – CROSS SECTION THROUGH RECEIVING & SOURCE ROOMS

8. Background Noise Levels

We chose to test the day before Anzac as the building site was devoid of any trades. This meant that ambient noise was at a minimum. The ambient noise levels were recorded at 30 dBA.

9. Considerations

It was possible to have the 60kg female walker with high heels walk upon the timber and tile floor areas. The sound was quite obvious. The higher 'click clack' of the high heels was more noticeable. The test results speak for themselves.

The tests revealed that the live walker on the carpet was pointless, as the carpet absorbed all impact sound. Even though the walker was a heavy walker, the technician pointed out again on the day that he could not audibly hear anything and therefore he believed that the sound level meter would have only picked up the ambient noise levels outside the room.

TABLE 18– ACOUSTIC TESTS CONDUCTED – DAY TWO – BUILDING SYSTEM D

TEST	Building System D	FLOOR SURFACE	TEST TYPE	DETAILS	DURATION
1	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	Tapping Machine position 1	Bruel & Kjaer 3207	180sec
2	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	Tapping Machine position 2	Bruel & Kjaer 3207	180sec
3	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	Tapping Machine position 3	Bruel & Kjaer 3207	180sec
4	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	Tapping Machine position 4	Bruel & Kjaer 3207	180sec
5	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	2.5kg rubber Grip Ball	110mm ball dropped from height of 1000mm high randomly	Ball was dropped for 90 seconds but recorded for 60 secs

6	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	85kg male walker with leather soled shoes	Walking in figure 8 and oval shape alternatively	Walked for 90 seconds but recorded for 60 seconds
7	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	60kg female walker with synthetic soled high heels	Walking in figure 8 and oval shape alternatively	Walked for 90 seconds but recorded for 60 seconds
8	D	Acousta Batten with 19mm blue gum flooring on 180mm 40mpa post tensioned slab with ceiling below & 150mm air cavity	85kg male walker with rubber soled shoes	Walking in figure 8 and oval shape alternatively	Walked for 90 seconds but recorded for 60 seconds
9	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	Tapping Machine position 1	Bruel & Kjaer 3207	180sec
10	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	Tapping Machine position 2	Bruel & Kjaer 3207	180sec
11	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	Tapping Machine position 3	Bruel & Kjaer 3207	180sec
12	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	Tapping Machine position 4	Bruel & Kjaer 3207	180sec
13	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	2.5kg rubber Grip Ball	110mm ball dropped from height of 1000mm high randomly	Ball was dropped for 90 seconds but recorded for 60 seconds
14	D	Porcelain tile floor on 180mm 40mpa post tensioned slab (no acoustic material) with ceiling & 350mm air cavity	85kg male walker with rubber soled shoes	Walking in figure 8 and oval shape alternatively	Walked for 90 seconds but recorded for 60 seconds

CHAPTER FIVE

TEST RESULTS – Concrete Slabs within the field and the laboratory

TABLE 19 – Dissimilar Floor / Ceiling Systems on Bare Concrete

FIELD & LABORATORY TESTS						
bare concrete slabs						
Bruel & Kjaer Tapping Machine	**Tapping Machine on dissimilar floor/ceiling systems on bare concrete**			Test results provided by Renzo Tonin & Associates		
	Type A System	**Type B System**	**Type C System**	**Field Test**	**Lab Test**	**Field Test**
Concrete slab	250mm 40 mpa slab	270mm 40 mpa slab	220mm 40 mpa slab on top of 50mm polystyrene/styrofoam	200mm concrete slab	200mm concrete slab	180mm concrete slab
Air Gap	150mm	no	no	no	no	80mm
Insulation	no	no	no	no	no	no
Ceiling	2 x 13mm standard plasterboard	22mm hardwood & exposed 45 x 195mm hardwood joists	22mm hardwood & exposed 45 x 195mm hardwood joists	no	no	1 x 13mm gyprock ceiling
L'_{nw} (C_i)					76 (-11)	
$L_{nt,w}$ (C_i)	63 (-11)	57 (-9)	58 (-9)	72 (-11)		58 (-10)
L'_{nw} C_i					**65**	
$L_{nt,w}$ C_i	**52**	**48**	**49**	**61**		**48**

Summary (results refer to $L'_{nT,w}$ C_i (field test) and L'_{nw} C_i (lab test).

Mass reduces noise. The thicker the slab the higher the reduction of noise attenuation into the apartment below. The 270mm slab (type B system) performs (no surprise) at $L_{nt,w}$ C_i 48. The 220mm slab (type C system), performs almost as well as the 270mm slab (type B) with addition of the 50mm polystyrene fill. The polystyrene acts the same way as insulation within a 50mm air qap.

250mm slab (type A system) does not perform as effectively as the 270mm thick slab (type B system) and yet there is only a 20mm mass difference with results of 52 dB and 48 dB respectively.

Type A System building had core filled concrete block load bearing walls either side of both the receiving and source rooms that were continuous vertically. Flanking would have been an influence on the results accounting for the slight increase in attenuation.

A 200mm concrete slab (Renzo Tonin) has laboratory results of $L'_{nT,w}$ C_i 65 and the same system tested in the field has yielded L'_{nw} C_i 61. The results have shown a difference of 4 dB difference in favour of the field test.

The 180mm concrete slab (Renzo Tonin) with air gap 80mm with 1 layer 13mm plasterboard show results of $L_{nt,w}$ C_i 48 equal with that of 270mm slab (type B system).

The 90mm difference in concrete density with the 22mm hardwood ceiling to the underside of the slab equals an 80mm airgap with one layer 13mm plasterboard.

TEST RESULTS – 2.5kg Grip Ball

TABLE 20 – 2.5kg Grip ball on 270mm, 220mm & 180mm concrete slabs, carpet, tile and timber flooring

				FIELD RESULTS						
	2.5kg Grip Ball on 270mm bare slab, tile & carpet compared with 220mm slab on 50mm polystyrene / styrofoam (dB readings only)									
	2.5kg ball was dropped randomly for 90sec from height of 1000mm									
	Type A System			Type B System		Type C System			Type D System	
Surface	Bare Concrete	Carpet	Tile	Bare Concrete	Carpet	Bare Concrete	Carpet	Tile	Tile	19mm bluegum hardwood
Acoustic Material	no	no underlay	4.5mm Acoustic Underlay	no	no underlay	no	no underlay	no acoustic material	no acoustic material	Acousta Batten & insulation
Concrete Slab	250mm concrete slab	250mm concrete slab	250mm concrete slab	270mm concrete slab	270mm concrete slab	220mm concrete slab on 50mm polystyrene / styrofoam	220mm concrete slab on 50mm polystyrene / styrofoam	220mm concrete slab on 50mm polystyrene / styrofoam	180mm concrete slab	180mm concrete slab
Air Gap	150mm	150mm	150mm	no	no	no	no	no	150mm	150mm
Insulation	no	no	no	no	no	no	no	no	no	no
Ceiling	2 x 13mm standard plasterboard ceiling	2 x 13mm standard plasterboard ceiling	2 x 13mm standard plasterboard ceiling	22mm hardwood and exposed 45 x 195mm hardwood joists	22mm hardwood and exposed 45 x 195mm hardwood joists	22mm hardwood and exposed 45 x 195mm hardwood joists	22mm hardwood and exposed 45 x 195mm hardwood joists	22mm hardwood and exposed 45 x 195mm hardwood joists	13mm standard plasterboard ceiling	13mm standard plasterboard ceiling
Suspended Ceiling	yes	yes	yes	n/a	n/a	n/a	n/a	n/a	yes	yes
Raw Data	**49 dB**	**49 dB**	**48 dB**	**44 dB**	**42 dB**	**45 dB**	**44 dB**	**42 dB**	**44 dB**	**51 dB**

Summary

There is very little difference between the results generated from a 2.5kg sand ball when dropped onto 270mm slab, 220mm slab with polystyrene fill and a 180mm concrete slab (type B, C & D systems) when a 2.5kg object drops onto the bare concrete. Both the 270mm concrete slab with a hardwood ceiling and the 180mm concrete slab with tile and a layer of 13mm plasterboard with air gap of 150mm perform identically of 44 dB. The 220mm concrete slab with 50mm polystyrene with a hardwood ceiling performs only 1 dB in difference of 45 dB.

If an object of this weight is dropped directly onto carpet, the difference between concrete and carpet is minimal. The decibel readings are quite consistent. On the 270mm concrete slab, there is only 2 dB difference between the bare concrete 44 dB and carpet 42 dB. On the 220mm slab with polystyrene fill, between bare concrete 45 dB and carpet 44 dB the difference is only 1 dB. On tile the reading was 42 dB. There is a difference of 3 dB from bare concrete to tile. We can assume therefore that the

8mm of tile, membrane and tile bed has been influential in reducing noise transmission of 3 decibels.

The biggest difference is evident between the 180mm concrete slab (type D system) with tile, 150mm airgap and 1 layer 13mm plasterboard with the 180mm concrete slab, 150mm airgap, 1 layer 13mm plasterboard, Acousta Batt, insulation and 19mm bluegum hardwood. The timber floor yields raw data of 51 dB. A difference of 7 dB. The Acousta Batten increases noise attenuation in comparison to the tile surface. (At the time, bare concrete was not accessible, otherwise we would have been able to compare the performance of bare concrete to both surface materials).
The results of the tests on the 250mm concrete slab (type A system) are consistently higher compared to the majority of test results from the other systems tested. We can only assume that flanking is an issue with system A where the loadbearing solid filled concrete block walls have an influence on noise attenuation.

When the ball drop on tile with System D is compared to the tile drop on System A, the latter system performs less well of 4 dB difference. System D had a discontinuous wall on one side and an exterior wall with cavity on the other.

A 4 dB difference is a doubling of noise intensity according to OSHA.

Overall, the results from the ball drop are relatively consistent across most surfaces such as bare concrete, tile, carpet and timber, although the timber floor has not performed as well as the other surface materials.

When comparing the results the following systems rank in order of effective noise attenuation:

1. Type B System
2. Type C System
3. Type D System
4. Type A System

Mass reduces noise attenuation and the ball demonstrates this quite evidently.

TEST RESULTS – Live Walker

TABLE 21 – Live Walker 85kg with leather soled & resin soled shoes

FIELD TESTS							
Live Walker 85kg with leather sole shoes							
	Type A System	Type A System	Type A System	Type D System	Type D System	Type D System	Type D System
	Leather Soled Shoe	Leather Soled Shoe	Leather Soled Shoe	Resin Soled Shoe		Leather Soled Shoe	
Surface Material	**Bare Slab**	**Carpet**	**Porcelain tile**	**Blue gum timber floor**	**Porcelain tile**	**Blue gum timber floor**	**Porcelain tile**
Acoustic Material		no underlay	4.5mm acoustic underlay	Acousta Batten with insulation	no acoustic underlay	Acousta Batten with insulation	no acoustic underlay
Walker	85 kg	85 kg	85 kg	85 kg	85 kg	85 kg	85 kg
Concrete slab	250mm 40 mpa slab	250mm 40 mpa slab	250mm 40 mpa slab	180mm 40mpa slab	180mm 40mpa slab	180mm 40mpa slab	180mm 40mpa slab
Air Gap	150mm	150mm	150mm	150mm	150mm	150mm	150mm
Insulation	no	no	no	no	no	no	no
Ceiling	2 x 13mm standard plasterboard	2 x 13mm standard plasterboard	2 x 13mm standard plasterboard	1 x 13mm standard plasterboard	1 x 13mm standard plasterboard	1 x 13mm standard plasterboard	1 x 13mm standard plasterboard
Suspended Ceiling	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Raw Data	**33 dB**	**30 dB**	**34 dB**	**33 dB**	**28 dB**	**34 dB**	**30 dB**

Summary

Professor Warnock stated that the type of shoe worn has an influence on the noise generated during walking and the shoes required needs to be leather, both in sole and heel (2-Warnock, 1998). The test results prove that leather sole shoes compared to resign soled shoes show a difference of at least 1 dB on a timber floor. On porcelain tile the difference is greater of 2 dB. Resin sole shoes do not impact on the floor as much as a leather sole shoe.

The results are generally consistent and walking on carpet at no surprise performs the best. Least well are the results generated from walking on tile.

Compared with high heel shoes, the leather soled shoes transfer sound in the lower frequencies. Compared with the ball drop, the walkers are less audible.

TEST RESULTS – Live Walker

TABLE 22 – Live Walker 60kg female with high heels

FIELD TESTS			
Live Walker 60kg with high heels on tile			
Type A System	**Type C**	**Type D**	**Type D**
Porcelain tile	Porcelain tile	Porcelain tile	19mm Bluegum Hardwood on Acousta Battens
4.5mm acoustic underlay	no acoustic material	no acoustic material	insulation
60 kg	**60 kg**	**60 kg**	**60 kg**
250mm slab	220mm slab on top of 50mm polystyrene / styrofoam	180mm slab	180mm slab
150mm	no	150	150
no	no	no	no
2 x 13mm standard plasterboard	22mm hardwood and exposed 45 x 195mm hardwood joists	1 x 13mm standard plasterboard	1 x 13mm standard plasterboard
Standard	no	Standard	Standard
38 dB	**39 dB**	**39 dB**	**35 dB**

Summary

High heels on porcelain tile show higher decibel readings than the results shown from walking on a timber floor. The difference being nearly 4 decibels. It is possible that either 1. the walker may tend to walk with less impact on timber, or that the timber may absorb noise due to the nature of the material.

Because tiles are a harder surface to timber, it is possible that when the hard plastic surface of the shoe within the ball of the foot contacts with tile, the noise is not only of a higher frequency but is slightly louder than the noise generated from a heavier walker of a leather soled shoe.

The results are very consistent on tile with systems A, C & D even though the structures and the systems are very different.

TEST RESULTS – Lab and Field Tests

TABLE 23 - Laboratory tests compared with field tests

	LABORATORY TESTS compared with FIELD TESTS					
	Tile Surfaces with various sized slabs, with & without ceilings					
	Laboratory	**Laboratory**	**Laboratory**	**Field**	**Field**	**Field**
Surface	8mm mono cuttura tile	10mm tile	10mm thick porcelain tile	10mm thick porcelain tile	10mm thick porcelain tile	bare concrete
Acoustic Material	5mm Rubber Underlay	3/6mm dimple acoustic underlay	4.5mm Rubber Underlay	4.5mm Rubber Underlay	no	-
Waterproof membrane	yes	yes	no	yes	yes	-
Screed	yes	yes	no	no	no	-
Concrete slab	140mm	170mm	170mm	250mm	220mm	200mm
Air Gap	-	-	-	150mm	50mm polystyrene fill	-
Insulation	no	no	no	no	no	-
Ceiling	no	no	no	2 x 13mm plasterboard	22mm hardwood tongue & groove	-
Suspended Ceiling	no	no	no	yes, standard		-
L'_{nw} (C_i)	65 (0)	62 (0)	62 (0)			
L'_{nw} C_i	**65**	**62**	**62**			
L'_{nTw} (C_i)				56 (-6)	58 (-9)	72 (-11)
L'_{nTw} C_i				**50**	**49**	**61**

Summary

What this series of results show, is unless extensive test results are compiled, it is very difficult to make an assumption because really, in effect, the results from this test means that one is comparing apples with oranges. Compiling data takes more time than this study has allowed.

This chart shows that it is necessary to know the structure when discussing systems in the field, because flanking can influence results. It is important to also have at least 2 or 3 similarities with materials or to understand the performance of the materials sufficiently enough in order to draw a more factual conclusion.

SUMMARY

Ascertain to what extent the acoustic upgrade to BCA 2004 has been in determining improved acoustic standards in medium to multi-density residential apartments as set out by the Australian Building Codes Board.

Prior to 2004, floors did not have a performance requirement and it was possible to have a worded description accepted. By introducing the '$L_{n,w} + C_I$ 62' the ABCB increased the performance of the building acoustically by at least 10dB and allowed for compliance for field testing to meet the standard.

The change has meant that suppliers can have a product tested within the laboratory to see whether it meets the compliance level as set by the ABCB i.e. suppliers can see very quickly if a product meets the requirement.

In Australia presently, the economic climate is all about the bottom line and thicker slabs means fewer apartments can fit within the vertical limit. The construction industry, is working against the positive influence structural mass can have on acoustic performance. The lighter the structure, the less foundation material required. But when the slab is reduced in thickness, acoustic products are required to achieve an increase in acoustic performance.

RESULTS

The results from the ball test are quite consistent, ranging from 44 dB to 51 dB across the majority of surfaces (vinyl excluded). The timber surface performed least well.

When comparing the live walkers, the higher frequency of the high heels on tile, results in an average of 39 dB compared to the leather soled shoes of the heavier walker on tile of 32 dB. High heels are very distinct. Both series of tests are relatively consistent.

Is the '$L_{n,w} + C_I$ 62' compliance rating, as dictated by the Australian Building Codes Board, an adequate acoustic performance criteria?

Put very simply, because this answer is covered in more depth in the final conclusion, it may be considered adequate by builders, but the general consensus by Acoustic Consultants, (as outlined in McCarthy's thesis), is that although the '62' compliance level is still too high, it is at least a good start (McCarthy, 2005).

Acoustic Specialists believe that buildings should have a star rating, whereby you can quite easily classify the acoustic, energy and comfort level of an apartment quite readily by categorising its performance.

The testing of acoustic materials within the laboratory, allows for the testing of individual products but this can make it difficult for the average person to understand how this number equates to an entire floor ceiling system. Many products can tend to espouse the effectiveness of the product, but how many products will put out comparative results with other products? How many suppliers will rate their product with various other ceiling / floor systems? Additionally, how many products also explain flanking issues, building quality and sometimes isolation systems that may be required to have the system work at maximum effectiveness?

Laboratory results can be unreal, in the way that materials are isolated and are not always tested as part of an entire system as this is costly. The laboratory slab for example is approximately 140-150mm thick and this size slab does not simulate the average sized slab in the commercial field that generally wavers around the 180mm plus sizing. Furthermore, a product cannot be seen in isolation, it needs to be married with the other building materials that make up the floor ceiling system.

I have shown that one particular system, does not yield the same test results within the laboratory and to that of the field (Renzo Tonin) and based on this one result, I have assumed therefore that results from the laboratory can only be an indicator of performance. The extent of this thesis, in regard to tests, has been limiting in terms of cost and time. More test results would prove the extent of the differentials over a range of materials and systems.

CHAPTER SIX

CONCLUSION

This chapter summarises the main issues and topics discussed from the literature review, the analysis and discussion of results from the case studies.

The main purpose of this study is to measure 'impact noise comparatives of floor / ceiling systems and to test the following hypothesis indicated in points 1, 2, 3 & 4.

The study has investigated;

1. The impact of dissimilar acoustic floor system on acoustic performance levels;
2. The performance of acoustic floor systems in the field compared to laboratory results of same or similar systems;
3. Ascertain to what extent the acoustic upgrade to BCA 2004 has been successful in determining improved acoustic standards in medium to multi-density residential apartments as set out by the Australian Building Codes Board;
4. Whether the '$L_{n,w}$ + C_I 62' compliance rating, as dictated by the Australian Building Codes Board, is an adequate acoustic performance criteria.

These issues will be discussed within this conclusive summary.

ACOUSTIC PERFORMANCE

Acoustic Performance is arguably the most important experiential and non-visual discriminator of quality homes and apartments. Owners and tenants are becoming increasingly aware of good acoustic performance, the difference it can make and what it means for living comfort (Powerscape, 2005).

Achieving complete silence in buildings is virtually impossible, and absolute silence is not usually necessary for acoustic comfort or peace to be experienced. It has been discussed that noise levels between 43 – 48 dB, provides for a happy occupant. Conversely a range between 58 – 63 dB results in an unhappy occupant which calls into question the '62' compliance level, as adopted by the ABCB.

Absolute silence may be necessary for music studios but not necessarily for a sole occupancy unit. Finding the level at which sound transmission is considered peaceful or non-irritating is very subjective and depends on many factors including; the type of noise, our mood, time of day, background noise levels and our expectations. (Powerscape, 2005).

According to McGowan's results within his chart titled 'Typical Noise Limits' (table 3), he states that within mainly residential areas, between 0700 – 1800 hours Monday to Friday, we should expect between 50 – 54 dB readings within our homes. Between the evening 1800 – 2200 hours the readings should be between 44 – 48 dB. At night between 2200 – 0700 hours the readings should be between 39 – 43 dB. On Sundays and public holidays between 0700 – 1800 hours the evening noise limits should apply of 44 – 48 dB. This is a vast difference to the Building Code of Australia's laboratory compliance level of $L'_{n,w}$ C_I 62.

OSHA's noise thermometer indicates the threshold of audibility at 20dB, a whisper at 30dB, 40dB is a quiet residential, library or office area, and a comfortable noise level range is 50dB. The Building Code of Australia's '62' rating is almost the equivalent of the sound that a sewing machine makes, a normal conversation or the rumble of a dishwasher.

TABLE 24 – STAR RATING RECOMMENDATION

Rating	Recommendation	AAAC Star Rating	Typical Noise Limits (McGowan, 2004)			Perception of impact noise in dwellings, Bruel & Kjaer				OSHA Noise Thermometer	
						dB	Normal Walking with normal footwear or house footwear	Elevated running children or walking barefoot	Extreme moving furniture and boisterous children	dB	Activity
	L'_{ntw}	L'_{ntw}	Mainly Residential Area							74	Vacuum Cleaner
1 star	62	65				63	Audible-intrusive	Very intrusive	Unbearable	60	Sewing Machine, Dishwasher, Normal Conversation
			dB	Time							
2 star	59	55	50-54	Day	0700-1800	58	Audible	Intrusive	Very intrusive	58	Microwave Oven
3 star	56										
4 star	53	50				53	Barely Intrusive audible	Audible			
5 star	50	45	44-48	Evening	1800-2200 including sundays & public holidays	48	Inaudible	Barely audible	Intrusive	50	Background music, Rustling paper, Transformer
6 star	47	40	39-43	Night	2200-0700	43	Inaudible	Inaudible	audible	43	Refrigerator
										40	Quiet Residential Area

The chart by Bruel & Kjaer (Table 5) identifies 63 dB as audible and intrusive when persons are walking normally with normal footwear within the source area. It shows the tolerance level decreasing when children are running or walking barefoot when the perception of the resulting noise becomes intrusive. When the noise generated from

the adjoining room is from boisterous children or furniture moving, the response is recorded as unbearable.
Decibel readings between 58 and 63 records the recipient response as unhappy, 53 dB as neutral and between 43 to 48 dB as happy. When occupants in the source room are walking normally with normal or house footwear, the chart indicates the noise level as being virtually inaudible.

There is currently no mandatory nationwide star rating that provides an indication of the performance of the building for the purchaser and / or the end user other than the star rating offered by the AAAC. Yet, when we wish to stay at a hotel, the performance of the hotel is always rated on a one to five star rating criteria. Why then should this not be applied to buildings?

BEING LESS NEIGHBOURLY

British noise pollution research suggests we get annoyed more easily because we are less neighbourly – having less social contact reduces our tolerance of neighbourhood noises. We are now decorating more sparsely, with a fondness of floorboards and tiles, indeed anything except carpets and heavy drapes that help block sound (Fyfe, 2003).

To reiterate, the trend, as we are experiencing it, is that our cities are being built up rather than out. Because executive apartments are becoming more costly, our expectations are higher. We need to contain and reduce noise in order to enjoy a healthy life and reduce our impact on others, particularly in high density areas (Greenhouse).

Although the BCA has set a minimum standard of L'_{nw} C_I 62, many members of the housing industry have interpreted this figure as an absolute requirement, applicable to all types of dwellings. The result has been that new owners of luxury apartments built to BCA standards have consequently become dissatisfied with the acoustic performance, because in their view, the level is not commensurate with the prices paid
i.e. sometimes in the millions (AAAC 2004).

According to Bruel & Kjaer, “In many countries, present building regulations operate with a limit of around 53 dB”.

The crux of this study is whether the ‘$L_{n,w}$ + C_I 62’ compliance rating, as specified by the Australian Building Codes Board, is an adequate acoustic performance criteria.

In my opinion, a more appropriate acoustic criteria would be a 6 star system associated with a relative decibel rating as indicated in the chart that I have compiled page 108. This would be far more meaningful and would allow designers, developers and builders to build to a desired level that could be certified by field tests. It would also allow for a common language whereby the purchaser would know that the apartment they were buying would meet the required acoustic comfort levels equal to the star rating.

This recommendation is in line with McGowan's expectations associated with the various times of day / night, with Bruel & Kjaer's investigation into the public perception of impact noise in dwellings, the AAAC star rating and OSHA's noise thermometer. According to OSHA, noise doubles in intensity every 3dB. In light of this, the recommendation is to marry every 3 dB increase to a star, from 62 dB as a one star, to 47 dB as a six star.

This study is required to ascertain what extent the acoustic upgrade to BCA 2004 has been successful in determining improved acoustic standards in medium to multi-density residential apartments as set out by the Australian Building Codes Board.

This study has revealed that there has not been sufficient time to gauge the response due to the fact that buildings post-2004 changes have either just been started or are still being built. All the buildings that were chosen to be field tested for this study, were the result of plans submitted subject to the pre-2004 changes.

This would be a good time to begin an investigation into the subjective responses of the occupants of newly completed buildings pre & post 2004 changes to judge more comprehensively whether the 10 dB increase is significant enough as far as the end user is concerned. This particular study would then be a precursor to a comprehensive look into end user tolerances, for example, various levels of noise output up to 85 dB in a range of moods, time of day and personal ages. Coupled with David McCarthy's Thesis – 'An Analysis of Builders, Designers and Supplier's opinions as to the suitability of the acoustical standards in BCA 2004 to reduce noise in multiple occupancy residential buildings'. Together the three studies could form an excellent basis for another review into the suitability of the current standard.

In my opinion, the increase by the ABCB in 2004 of 10dB is only a marginal increase relative to a one star rating. Only by collecting and analysing subjective responses to raw data generated by floor impact noises could there be an assumption drawn as to whether the 10dB has been significant to reduce complaint, annoyance and litigation on the one hand or increase acceptance and comfort on the other.

Robert Caulfield of Archicentre within the RAIA, (building advisory service of the Royal Australian Institute of Architects) asserts “we are increasingly being asked to look at noise problems in apartments, units and flats. The main issue is that people have committed to purchase the property or have moved in before they carry out a noise assessment (RAIA, 2003). In a direct conversation with Robert Caulfield, whereby he gave verbal permission to quote him directly he stated for the record “No-one really knows the magnitude of the problem, and that it has been almost impossible to get anecdotal data pertaining to the quantity of litigious cases surrounding noise transmission in apartments. When something is brand new, the purchasers’ expectations are higher than subsequent owners. We have a continual stream of complaints and enquiries of at least 1-2 each week” (Caulfield).

ACOUSTIC TESTING - Laboratory

The CSIRO laboratory in Australia promotes a standard concrete slab of 150mm in thickness and is incapable of exchanging the slab with depths of 180mm and higher because the mechanical equipment required to swap slabs cannot physically take the additional weight. Thicker slabs are more common in the field. Not only does this accredited laboratory provide limited slab sizes that simulate structural thicknesses more suited to Class 1 buildings, the costs associated can be formidable and anything unusual can not be accommodated.

Australia needs a laboratory that can be more flexible when various structural types are required to be replicated. This laboratory was not able to simulate the systems that I have tested in the field, (180mm, 250mm, 220mm concrete slabs) as the equipment is not capable of lifting to that capacity.

Because the lab is a perfect environment that is rarely duplicated in everyday applications in Class 2 buildings, it has been assumed that some materials will have results equivalent to that in the field. This is not necessarily the case. Furthermore, entire systems have not been mandatory in the laboratory, because the L'_{nw} C_i 62 criteria has been so easy to achieve without the need for ceilings and air cavities if it is a surface product and vice versa. I have shown that a 200mm bare concrete slab in itself, can achieve a rating in the field of L'_{nw} C_i 61.

Simulations are conducted in laboratories because they offer controlled conditions. But many variables can occur in the field. The variables that can influence the performance of systems or acoustic materials are as follows:

- thickness of the slab

- thickness of the timber floor structure
- joist type, spacing and depth
- air space cavity
- insulation density
- volume and configuration of the room(s)
- time of day and temperature variants
- background noise levels i.e. external traffic, wind and rain
- building structure types and various acoustic systems
- construction quality
- surface treatments and materials within the rooms
- penetrations
- noise flanking

By understanding how materials and systems perform independently and comparatively is it possible to understand and / or anticipate how systems might perform. Also, ambient noise levels impact on subjective response to impact noise.

Part of this study is to 1. examine the impact of dissimilar acoustic floor system on acoustic performance levels; and to 2. investigate the acoustic performance of acoustic floor systems compared to laboratory results of same or similar systems.

FIELD AND LABORATORY TESTING

This study has incorporated the comparison of results from a range of surfaces such as concrete slabs, tiles, carpet and timber. The surfaces and systems were tested with a tapping machine, 2.5kg sand ball and two live walkers - 85kg with leather sole & 60kg with high heels.

Tapping Machine – on a bare concrete slab

One criticism made of the standard tapping machine is that the steel hammers do not properly simulate a human foot. Although there is no standard method in Australia for measuring the sound pressure levels generated by a person walking on a floor, certain techniques have been developed in Japan to accommodate a 'standard walker' whereby the walker is required to generate a constant sound pressure level when walking on the floor.

Mass reduces noise. The thicker the slab the higher the reduction of noise attenuation into the apartment below. The 270mm slab (type B system) performs (no surprise) at $L_{nt,w}$ C_i 48. The 220mm slab (type C system), performs almost as well as the 270mm slab (type B) with addition of the 50mm polystyrene fill. The polystyrene acts the same way as if it were insulation within a 50mm air qap.

250mm slab (type A system) does not perform as effectively as the 270mm thick slab (type B system) and yet there is only a 20mm mass difference with results of 52 dB and 48 dB respectively.

Type A System building had core filled concrete block load bearing walls either side of both the receiving and source rooms that were continuous vertically. Flanking would have been an influence on the results accounting for the slight increase in attenuation.

A 200mm concrete slab (Renzo Tonin) has laboratory results of $L'_{nT,w}$ C_i 65 and the same system tested in the field has yielded L'_{nw} C_i 61. The results have shown a difference of 4 dB difference in favour of the field test.

The 180mm concrete slab (Renzo Tonin) with air gap 80mm with 1 layer 13mm plasterboard show results of $L_{nt,w}$ C_i 48 equal with that of 270mm slab (type B system). The 90mm difference in concrete density with the 22mm hardwood ceiling to the underside of the slab equals an 80mm airgap with one layer 13mm plasterboard.

2.5kg Sand Ball

Recent studies have proven that jumping noise was the most frequently produced sound during an adult walking and a child playing in a multi-story residential building (Jeon et al, 2002).

Figure 2 demonstrated that jumping in the maximum sound pressure level is similar to that of the bang machine and the ball. The rubber ball drop is particularly close to the noise generated from actual live jumping and therefore it is possible to simulate this sound when studying the subjective response of occupants for a comprehensive look into end-user responses.

There is very little difference between the results generated from a 2.5kg sand ball when dropped onto 270mm slab, 220mm slab with polystyrene fill (both with hardwood ceilings) and a 180mm concrete slab with tile (plaster ceiling) (all 40mPa) when a 2.5kg object drops onto the bare concrete. Without going into too much detail (because more comprehensive results are in chapter 5) both the 270mm concrete slab with a hardwood ceiling and the 180mm concrete slab with tile and a layer of 13mm plasterboard with air gap of 150mm perform identically of 44 dB. The 220mm concrete slab with 50mm polystyrene with a hardwood ceiling performs only 1 dB in difference of 45 dB.

If an object of this weight is dropped directly onto carpet, the difference between concrete and carpet is minimal. The decibel readings are quite consistent. On the 270mm concrete slab, there is only 2 dB difference between the bare concrete 44 dB and carpet 42 dB. On the 220mm slab with polystyrene fill, between bare concrete 45 dB and carpet 44 dB the difference is only 1 dB. On tile the reading was 42 dB. There is a difference of 3 dB from bare concrete to tile. We can assume therefore that the 8mm of tile, membrane and tile bed has been influential in reducing noise transmission of 3 decibels.

The biggest difference is evident between the 180mm concrete slab with tile, 150mm airgap and 1 layer 13mm plasterboard with the 180mm concrete slab, 150mm airgap, 1 layer 13mm plasterboard, Acousta Batt, insulation and 19mm bluegum hardwood. The timber floor yields raw data of 51 dB. A difference of 7 dB. The Acousta Batten increases noise attenuation in comparison to the tile surface. (At the time, bare concrete was not accessible, otherwise we would have been able to compare the performance of bare concrete to both surface materials).

Walkers

Robert Caulfield has stated that dropping items onto tiles, the click clack of womens high heels and loud stereos seem to be, in his experience, the sounds complained about the most. Also the type of shoe worn has an influence on the noise generated during walking and the shoes required need to be leather, both in sole and heel. The noise generated from the male walker of approximately 85kg with leather shoes is not only compared to the same walker with resin sole shoes but is also compared to the 60kg female walker with synthetic high heels.

High heels on porcelain tile show higher decibel readings than the results shown from walking on a timber floor. The difference being nearly 4 decibels. It is possible that either 1. the walker may tend to walk with less impact on timber, or that 2. the timber is absorbing the noise difference due to the nature of the material.

Because tiles are a harder surface to timber, it is possible that when the hard plastic surface of the shoe within the ball of the foot contacts with tile, the noise is not only of a higher frequency but is slightly louder in decibels than the noise generated from a heavier walker of a leather soled shoe. The results are very consistent on tile with systems A, C & D even though the structures and the systems are very different.

Professor Warnock stated that the type of shoe worn has an influence on the noise generated during walking and the shoes required needs to be leather, both in sole and heel (2-Warnock, 1998). The test results prove that leather sole shoes compared to resin soled shoes show a difference of at least 1 dB on a timber floor. On porcelain tile the difference is greater of 2 dB. Resin sole shoes do not impact on the floor as much as a leather sole shoe.

The results are generally consistent and walking on carpet at no surprise performs the best. Least well are the results generated from walking on tile. Compared with high heeled shoes, the leather soled shoes transfer sound in the lower frequencies. Compared with the ball drop, the walkers are less audible.

PREDICTIONS

Australia is in need of a comprehensive body of data that includes laboratory test results, field test results and the subjective responses of occupants to be more widely available. Even though Dr Warnock discusses the STC and IIC classes in the following statement, the principle remains the same. He states that predications can be made to determine the sound transmission class and impact insulation class with sufficient accuracy by simple regression analysis using variables such as the mass of the layers, joist depth and spacing, insulation thickness, density and resilient metal furring spacing (also known as resilient mounts), (5-Warnock 2000) in order to predict the performance of materials within complete floor / ceiling systems.

An actual site test should only confirm and certify the performance of a complete system for the relative authority to ensure the building is built to the star rating required or expectations of the end user.

Unlike Canada, Australian data for impact noise transference has been difficult to obtain as acoustic professionals espouse ‘commercial-in-confidence’. Suppliers are wary of revealing comprehensive and comparative results in order to maintain an edge within competitive markets and may only provide information on a ‘need to know’ basis. Data, if compiled, would provide better indicators and valuable baseline data (EPA). This veiled response to retaining information needs to change.

What this series of results has shown, is unless an extensive list of test results is compiled, it is very difficult to make objective predictions on performance for various materials and systems because often the scenarios are so different that results from tests means that one is comparing apples with oranges. Compiling an extensive compendium of factual and relevant data takes more time than this study has allowed.

It is also necessary to know the structure well when discussing systems in the field, because flanking influences results. It is important to also have at least 2 or 3 similarities with materials to understand how well materials perform in the field.

Laboratory results vary to field tests. Materials are isolated and are not always tested as part of an entire system as this is costly. The laboratory slab for example is approximately 140-150mm thick and this size slab does not simulate the average sized slab in the commercial field that generally wavers around the 180mm plus sizing. Furthermore, a product cannot be seen in isolation, it needs to be married with the other building materials that make up the floor ceiling system.

I have shown that one particular system, does not yield the same test results within the laboratory to that of the field (Renzo Tonin) and based on this result, I have made the assumption therefore that results from the laboratory can only be an indicator of performance.

The extent of this thesis, in regard to tests, has been limiting in terms of cost and time. To reiterate what I have said earlier, more test results, or test results gathered from acoustic professionals would prove the full extent of the differentials in order to be of benefit to acoustic professionals, the building industry and to the general public. To reiterate what I have said earlier the ABCB needs to consider providing a compliance scale relative to a 6 star rating as offered by the AAAC.

There is currently no mandatory nationwide star rating that provides an indication of the performance of the building for the purchaser and/or the end user other than the star rating offered by the AAAC. Yet, when we wish to stay at a hotel, the performance of the hotel is always rated on a one to five star rating criteria. This needs to be applied to buildings.

By also establishing an average tolerance level from a range of people, in a range of apartments categorised into the AAAC's star rating system, I believe this information would be of huge benefit when reviewing what is an acceptable noise level emission. This may address the issue of noise transmission in medium to high rise apartments in Australia where purchasers are more informed about what level of building they are buying. This may allow purchasers to purchase an apartment relative to their average tolerance level and have architects and builders design and build to the star rating that the market expects or demands.

EPILOGUE

The AAAC classification rating is determined by the lowest score awarded. Ideally scores should be given for not only impact sound but also for Services Noise Insulation as well as Airborne Sound Insulation. But that investigation is beyond the scope of this research.

Government research into how Australian structures perform acoustically provides not a lot of funding and this needs to change. When you compare what information is available publicly in Australia, it is vastly destitute compared with the information that proliferates from Canada.

Dr Warnock has managed to test as many as 190 lightweight joist floors with different joist types, sub-floors, ceiling types, ceiling support systems and so on. Because of Australia's building construction is similar to Canada, it would be an interesting exercise to draw comparisons conducted by the NRC to acoustic performance between structures of a similar types, materials and systems from Australia.

Knowing and identifying the variables and how they can influence acoustic performance will go a long way in the understanding of how structural variations and installation details can make a difference. A comprehensive study in this area would provide a broad outline of what to expect in the most basic of scenarios. To be able to predict performance levels of complete systems in Australia, in a range of complexities would again be of benefit to the industry

RECOMMODATIONS FOR FURTHER STUDY

The following areas would warrant further study:

1. A subjective study of the opinions of occupants of buildings at various times of the day;
2. Comparative field studies with various structures and materials in countries such as New Zealand, Canada and the UK;
3. Comparative field studies that reveal the extent that external factors influence field test results i.e. wind, rain and temperature variants;
4. Comparative field studies on concrete slab structures from date of pour to gauge the effects that moisture may have on field results;
5. To field test at different times of day and night;
6. To field test post-occupancy i.e. when the rooms are furnished.
7. Compile comprehensive data on bare slabs, bare slabs with ceiling, bare slabs with various ceiling cavity depths, bare slabs with various ceiling types, slabs with all mentioned with various surface treatments i.e. carpet, carpet & underlay, vinyl, tile & timber finishes.
8. Compile comprehensive data on timber floor ceiling structures.
9. Study the influence various room configurations impact on noise attenuation.
10. Study flanking issues with various construction wall types.

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ASSOCIATIONS

Home Unit Owners Association (NSW), PO Box 52, Cronulla, NSW, Australia (02) 9527 4146

Association of Australian Acoustical Consultants

Australian Acoustical Society

Australian Building Codes Board

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www.acoustics.com "What does sustainable design sound like?"
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www.powerscape.com ""Powerscape Peace Concrete" CBI5113
www.acu-vib.com.au "Acu-Vib Electronics"
Acu-Vib Electronics is an Australian company. They specialize in the **Sales, Calibrations, Hire & Repairs** of high quality electronic test equipment for use in the fields of Acoustics & Vibrations, Occupational Health & Safety, Environmental, Research and Development.

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(Aerodynamic Developments P.L. is an Australian company incorporated in 1970. They are located in Wetherill Park in the west of Sydney, occupying factory space utilised for the storage and distribution of Styrofoam, Kemlite and other products).

Photographs of CSIRO acoustic laboratory Melbourne with permission from
Rex Broadbent.

ArchiCAD Student Version software system to simulate the axonometrics of the apartments.

DEFINITION OF TERMS

ACOUSTICS: Science dealing with the production, effects and transmission of soundwaves.

ACOUSTIC QUALITY: A quantified rating based on attribute of the room acoustics.

AIRBORNE SOUND: This relates to sound waves originating in the air from sources such as amplified stereo systems and voices that produce sound waves caused by fluctuations in air pressure.

AMENITY: relates to the qualities, characteristics and attributes people value about a place and which contribute to their experience of 'quality of life'.

BUILDING CLASS: An organised system produced by the BCA that pertains to the classification of a building for which it is designed, constructed or adopted use.

BUILDING CODE OF AUSTRALIA: Is a uniform set of technical provisions for the design and construction of buildings and other structures within Australia. It is produced and maintained by the Australian Buildings Code Board (ABCB) on behalf of the Commonwealth and each State and Territory Government.

C_I, C_{tr} SPECTRUM ADAPTATION TERM: A value, in decibels, to be added to a single number rating (eg R_w, L'_{ntw},) to take account of the characteristic of particular sound spectra. C_{tr} allows for low frequency noise like DVD and HiFi/TV sound, and C_I for footfall on floors.

dB(A) DECIBEL: The basic unit of sound pressure level, modified by the A-weighting network to represent the sensitivity to the human ear. A change of 1dB in sound pressure is the smallest change that can be detected by the human ear. 0 dB is the threshold of hearing and 120 dB is the threshold of pain.

Hz FREQUENCY IN HERTZ: The human ear responds to sound in the frequency range of 20 Hertz to 20,000 Hz. A combination of sound pressure and frequency determine perceived loudness. The centre frequency of an octave is double the frequency of the lower octave. Sound measurements are usually taken at 16 one-third- octave bands between 100 and 3150 Hz.

IMPACT SOUND: Impact or structure borne sound, relates to the vibration of sources like mechanical plant or the direct impact of a solid object on a surface of the structure in which vibrations are sent throughout the building structure and thus creating sound waves.

IMPACT SOUND INSULATION: Characteristic of a building element to reduce sound resulting from direct impact on the building element.

L SOUND PRESSURE LEVEL: The sound pressure, measured in decibels, for one-third octave bands, recorded in the receiving rooms of a laboratory sound insulation test.

$L'_{nt,w}$ WEIGHTED STANDARDISED IMPACT SOUND PRESSURE LEVEL: Single number rating of impact sound insulation between dwellings tested on site. A lower value provides better insulation.

$L_{n,w}$ WEIGHTED NORMALISED IMPACT SOUND PRESSURE LEVEL: Single number rating of impact sound insulation property of a floor tested in a laboratory. A lower value provides better insulation.

NOISE: Unwanted and undesirable soundwaves that become a source of annoyance.

NOISE CONTROL: Is the understanding of the noise producing sources or mechanisms and producing a system to efficiently control the noise to acceptable levels for the occupants of the building. It may involve the use of a barrier to insulate.

R SOUND REDUCTION INDEX: A measure of airborne sound insulation calculated from the ratio of the sound power incident on a partition to the sound power transmitted through the partition.

Rw WEIGHTED SOUND REDUCTION INDEX: A single figure rating, in decibels, for the airborne sound insulation of a building element calculated from the range of R values tested in a laboratory. A higher value provides better insulation.

REGULATION: Given legal effect by the building regulatory legislation in each State and Territory.

SOUND ATTENUATION: The reduction of noise.

SOUND INSULATION: The reduction of impact or airborne sound energy achieved by a barrier i.e. partition, single or double, which separates a noise source from another area.

SOUND LOSS: Refers to the level in decibels of the loss of the soundwaves energy from one room to another.

SOUND TRANSMISSION: Is the fraction of sound energy that transmits through a wall for example. Otherwise known as the transmission co-efficient. Most sound energy is reflected back off the wall back into the room from which the noise was created.

STAKEHOLDER: Any person who has a vested interest in a particular issue.

DEFINITIONS of the terms used within the Australian/New Zealand and International Standard for Field measurements if impact sound insulation of floors AS/NZS ISO 140.6:2006

For the purpose of part ISO 140.6:2006, the following definitions apply.

Average Sound Pressure Level in a room, *L*: Ten times the logarithm to the base 10 of the ratio of the space and time average of the sound pressure squared to the square of the reference sound pressure, the space average being taken over the entire room with the exception of those parts where the direct radiation of a sound source or the near field of the boundaries (wall etc) is of significant influence; it is expressed in decibels. (Refer to standard for the calculation).

Impact Sound Pressure Level, L_i*:* Average sound pressure level in a one-third-octave band in the receiving room when the floor under test is excited by the standardised impact sound source; it is expressed in decibels.

Normalized Impact Sound Pressure Level, L_n*:* Impact sound pressure level L_i increased by a correction term which is given in decibels, being ten times the logarithm to the base 10 of the ratio of the measured equivalent absorption area A of the receiving room to the reference absorption area A_o; it is expressed in decibels.

$$L_n = L_i + 10 \lg \frac{A}{A_o} \text{ dB}$$

With $A_o = 10\ m^2$

For the purpose of this part of ISO 140.7:1998, not only do the average, impact and normalized impact sound pressure levels apply, but also the following definitions below:

Standardized impact sound pressure level, L'_nT: Impact sound pressure level L_i reduced by a correction term which is given in decibels, being ten times the logarithm to the base 10 of the ratio of the measured reverberation time *T* of the receiving room to the reference reverberation time T_o; it is expressed in decibels:

$$L'_nT = L_i - 10 \lg \frac{A}{A_o} \text{ dB}$$

For the purpose of this part of AS ISO 717.2 - 2004, the following definitions apply.
Single-number quantity for impact sound insulation rating derived from one-third-octave band measurements: Value, in decibels, of the relevant reference curve at 500 Hz after shifting it in accordance with the method specified in this part of ISO 717.

Single-number quantity for impact sound insulation rating derived from octave band measurements: Value in decibels, of the relevant reference curve at 500 Hz after shifting it in accordance with the method specified in this part of ISO 717, reduced by 5 dB.

Weighted reduction in impact sound pressure level: Difference between the weighted normalized impact sound pressure levels of a reference floor without and with a floor covering, obtained in accordance with the method specified in this part of ISO 717. This quantity is denoted by ΔL_w and is expressed in decibels.

Spectrum adaptation term, C_I: Value, in decibels, to be added to the single-number quantity to take account of the unweighted impact sound level, thereby representing the characteristics of typical walking noise spectra.

Equivalent weighted normalized impact sound pressure level of a bare massive floor: Sum of the weighted normalized impact sound pressure level of the bare floor under test with the reference floor covering and the weighted reduction in impact sound pressure level of the reference floor covering obtained in accordance with the method specified in this part of ISO 717. This quantity is denoted by $L_{n,eq,0,w}$ and is expressed in decibels.

ABBREVIATIONS

AAAC	Association of Australian Acoustic Consultants
ABCB	Australian Buildings Code Board
AS	Australian Standard
BCA	Building Code of Australia
CIOB	Construction Institute of Building
DCP	Development Control Plan
EPA	Environmental Protection Authority
ISO	International Standards Organisation
JIS	Japanese Standard
LEP	Land & Environmental Protection also in association with the local Council; also known as Local Environment Plan
MBA	Master Builder's Association
NSW	New South Wales
NTS	Not to Scale
NZS	New Zealand Standard
OSHA	Occupational Safety and Health Administration (USA)
POEO	Protection of the Environmental Operations
SPL	Sound Pressure Level

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mm	millimetre
mPa	megapascal
m	metre

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Test Results

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APPENDIX 11

Ethics Approval