IMPROVING THE SOUND INSULATION AND SUSTAINABILITY OF TIMBER-FRAMED FLOORS.

GRANT EMMS, BARBARA NEBEL

Scion, Private Bag 3020, Rotorua, New Zealand.

ABSTRACT

Lightweight, timber-framed multistorey, multi-residential housing can have a number of advantages over massive construction in terms of cost and construction time. However, one of their major problems, as perceived by occupants, is their poorer insulation of low-frequency sound; particularly the insulation of low-frequency impact sounds from floors. The poorer low-frequency impact sound insulation performance of timber-framed floors has reduced the number of multistorey, multi-residential timber-framed constructions. This paper looks at timber-framed floor designs which have improved low-frequency impact sound insulation. We consider sound insulation performance, cost and environmental life cycle assessment of a number of floor designs. We also look at ways to reduce the environmental impacts without compromising the acoustic performance of the floor.

KEYWORDS:

Timber-frame; Floors; Environmental Life Cycle Assessment; Acoustics.

INTRODUCTION

Current occupier perception of timber intertenancy floor/ceiling systems used in Australasia is that they do not perform acoustically as well as heavy masonry building systems, particularly in terms of low-frequency impact sound transmission from the floor above. This perception has resulted in a limit in growth of multi-residential timber apartments in Australasia. Concern for this problem and an expectance of a growth in medium-rise apartment construction has resulted in increased Australasian research into this problem. This concern is not unique to Australasia, and as a result, a number of other countries with an interest in timber housing construction have also been researching this problem (e.g. Blazier & DuPree, 1994; Hveem , 1998) A team of New Zealand building acoustics researchers and Australasian companies and associations (NZPMA, CSR, Gib, CHH, Tenon) formed a consortium to tackle this project with part funding from the FWPRDC of Australia. This project essentially consisted of progressing existing Australasian and overseas research into this problem with a view to produce floor/ceiling system design recommendations for floors having acoustic properties which are comparable with concrete floor constructions, while also meeting the proposed Australian and New Zealand building code requirements, and being cost effective and buildable using existing construction industry skills (Emms et al., 2006).

Timber-framed constructions can have a number of advantages over concrete constructions, including less cost, and greater construction speed. Another supposed advantage of timber-framed construction, which is sometimes put forward, is a reduced environmental impact. In this paper we extend the research done previously by assessing an aspect of the environmental impacts of some timber-framed floor systems and compare them to a concrete system. The environmental impact of each floor is assessed by performing a life cycle assessment in terms of the global warming potential and the cumulative energy demand.We also then show how LCA principles can be assist designers to make informed choices by identifying environmental impact hotspots which can be altered without greatly affecting our other performance criteria.

The aim of the paper

The aim of this paper is to present a case study which looks at how life cycle assessment can be incorporated with other building design aims (viz. in this case acoustic insulation) to select more appropriate building systems.

The paper is divided into two aspects:-

1) Improving the low-frequency impact sound insulation performance of floors.
2) Assessing the economic and environmental life-cycle cost of various potential floor designs.

Aspect (1) concerns the frequency range of sound below about 100 to 200Hz. It is in this low-frequency range that problems arise in a number of areas. For one thing, this is the area that lightweight floor systems have problems compared to heavy floor systems due to their light weight and perhaps their lower stiffness. It has been found by experience over the world that intertenancy lightweight floors tend to be regarded as poor performers by occupiers in the neighbouring tenancy (usually the tenancy below). This poor performance is often expressed by occupiers as the hearing of 'bumps and thumps' from above and is due to poorer low-frequency impact insulation. In part, this has presumed to have been caused by people walking or otherwise moving around on the floor above. Another contribution to these low-frequency 'bumps and thumps' can be things such as doors closing or heavier objects being dropped. On the other hand, heavy masonry systems, from experience, appear to perform 'acceptably' in this area of low-frequency impact insulation.

High frequency (above 200Hz) impact insulation is also important, but it is something which is relatively easy to deal with and measure, having received much attention from researchers and industry.

Aspect (2) concerns the economic and environmental performance of different floor designs.

The economic costs are generally based on data from the Australian Construction Handbook 2005 issued by Rawlinsons, and apply to construction in Sydney. The costs are given for the building element (per m^2), and hence do not consider the whole building cost. It should be noted that the choice of floor type can influence the whole building cost, e.g. lightweight construction results in less foundation requirements and hence less overall cost. The whole building cost was not estimated due to the greater complexity of doing so, and due to the greater number of variables involved.

Two indicators have been chosen for the environmental assessment; the cumulative energy demand and the global warming potential. The cumulative energy demand is sometimes described as 'embodied energy'. However, the term cumulative energy demand provides a better description of this indicator, which represents all energy required for the manufacture and transport of a product. The related green house gas emissions are expressed as kg CO_2 equivalents. These indicators in combination provide a good overview of the environmental impacts. They are also the indicators which are currently suggested to be included in the new building code.

This paper demonstrates how they can be used to assess different building components. The paper also shows how environmental hotspots in specific designs can be detected and might be improved.

The data used for the environmental assessment performed in this case study is based on a European dataset. The dataset is part of the LCA software GaBi 4.2 (GaBi). The dataset is in itself consistent and therefore allows a fair analysis and comparison of the different design options. The generic principles of using LCA in a design process can be demonstrated without any constraints. Although the direct applicability of the results in New Zealand is somewhat restricted (Nebel 2007), it is valid to conclude general trends from results based on international data.

IMPACT SOUND INSULATION PERFORMANCE

The problem of the impact insulation performance of floors can be divided into a number of factors which influence the overall result; these are illustrated in Figure 1.
The first factor is the impact source itself. The issue here is to know which impact sources represent activities that happen in apartments, or at least, ultimately produce a result which ranks floors according to the occupiers' opinions.
The second factor is the reaction of the floor to impact forces imposed on it. The reaction we are primarily concerned with is how the ceiling of the floor vibrates in response to the impact forces. The issue here is to produce floor designs which minimise the ceiling vibrations which produce offending sounds for the impacts that typically occur in apartments.
The third factor is the influence of the room on the sound generated by the ceiling vibrations. It is important to realise that the so-called receiving room itself is a highly influential factor in sounds that are produced by the ceiling vibrations. This is particularly so for low-frequency sounds.
The fourth factor is the psychoacoustic response of the occupants in the receiving room below the floor. This factor is how the occupiers react to the sounds that are produced in the receiving room. This subjective aspect of the problem is important to determine how well floors and sounds generated by impacts on them perform compared to other floors (i.e. how they can be ranked). This is possibly the most important factor of the acoustic insulation problem, but is also possibly the most nebulous.

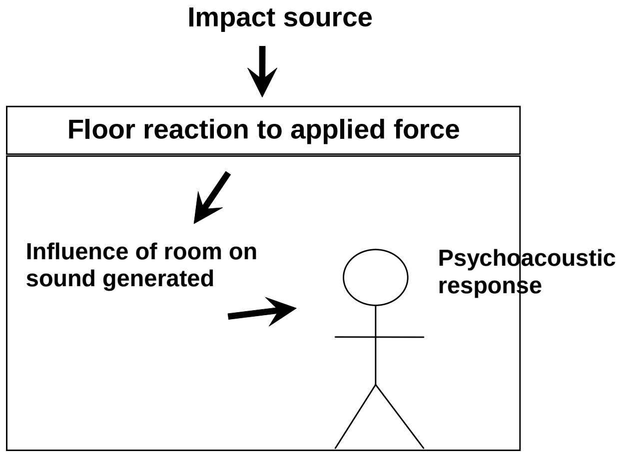

Figure 1. Diagram illustrating the breakdown of the acoustic problem into factors influencing the outcome.

Results of impact sound insulation performance research.

Based on existing knowledge and theoretical examination, a number of floors were built and tested for impact insulation performance. For the purpose of this paper, we selected a number of timber-framed floors with varying degrees of acoustic, low-frequency impact sound insulation performance. These floor designs are:–

- Basic, timber-framed intertenancy floor – a 'basic' intertenancy floor which, with the addition of carpet performs acceptably in terms of its high-frequency impact insulation performance, and meets building code requirements for both acoustic and fire resistance. The low-frequency impact insulation performance, however, is not good. (See Figure 2).
- Gypsum-fibreboard topped floor. The low-frequency acoustic performance of the 'basic', timber-framed floor is improved by adding mass to the floor in the form of gypsum fibreboard sheeting. (See Figure 3).
- Aerated concrete topped floor. Extra mass is added to the floor by topping the joists with aerated, autoclaved concrete instead of plywood or particleboard. (See Figure 4).
- Sand-filled floor. Extra mass and damping is added to the floor by creating another cavity on the top of the floor and filling this cavity with a sand/sawdust mix. (See Figure 5).

- Floating gypsum concrete topped floor. Extra mass and isolation is provided by floating a gypsum concrete screed on top of resilient foam or matting. This type of floor system is common is North America. (See Figure 6).
- 150mm concrete slab floor with ceiling. This floor is not a timber-framed floor, but is used as a type of bench mark comparison, since its low-frequency impact sound insulation performance is deemed to be good. (See Figure 7).

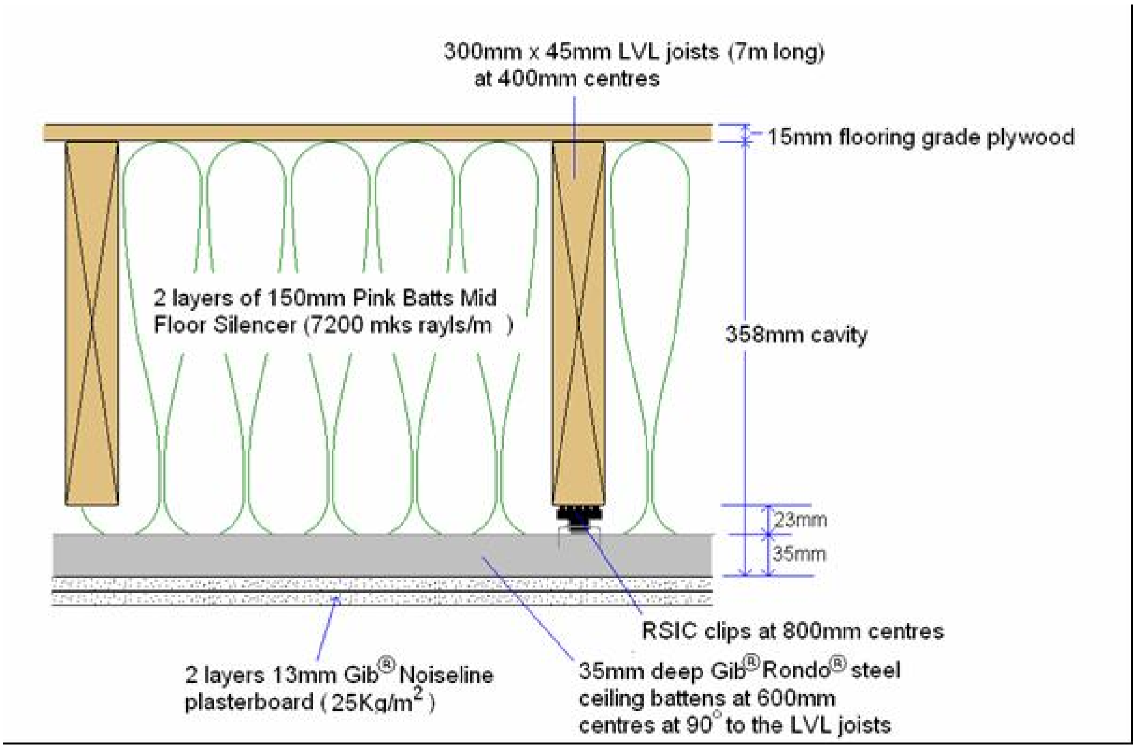

Figure 2. Basic, timber-framed intertenancy floor.

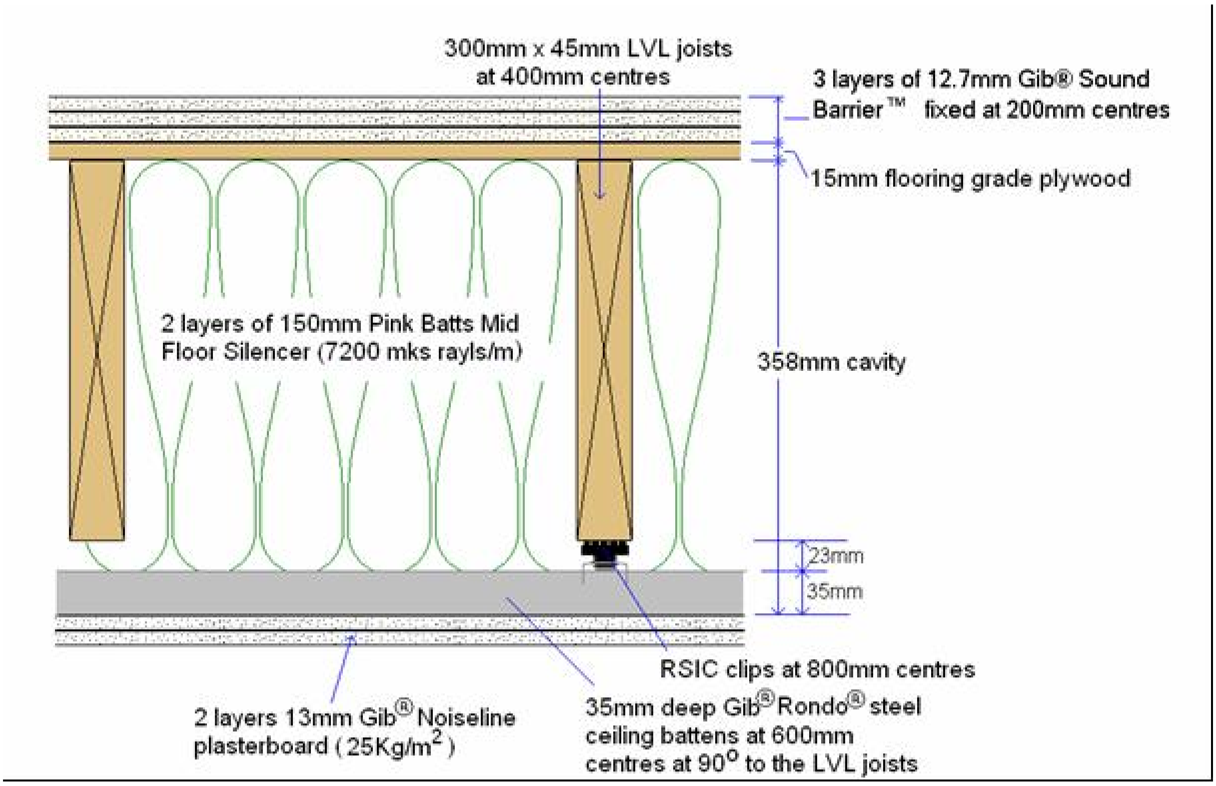

Figure 3. Gypsum fibreboard topped floor.

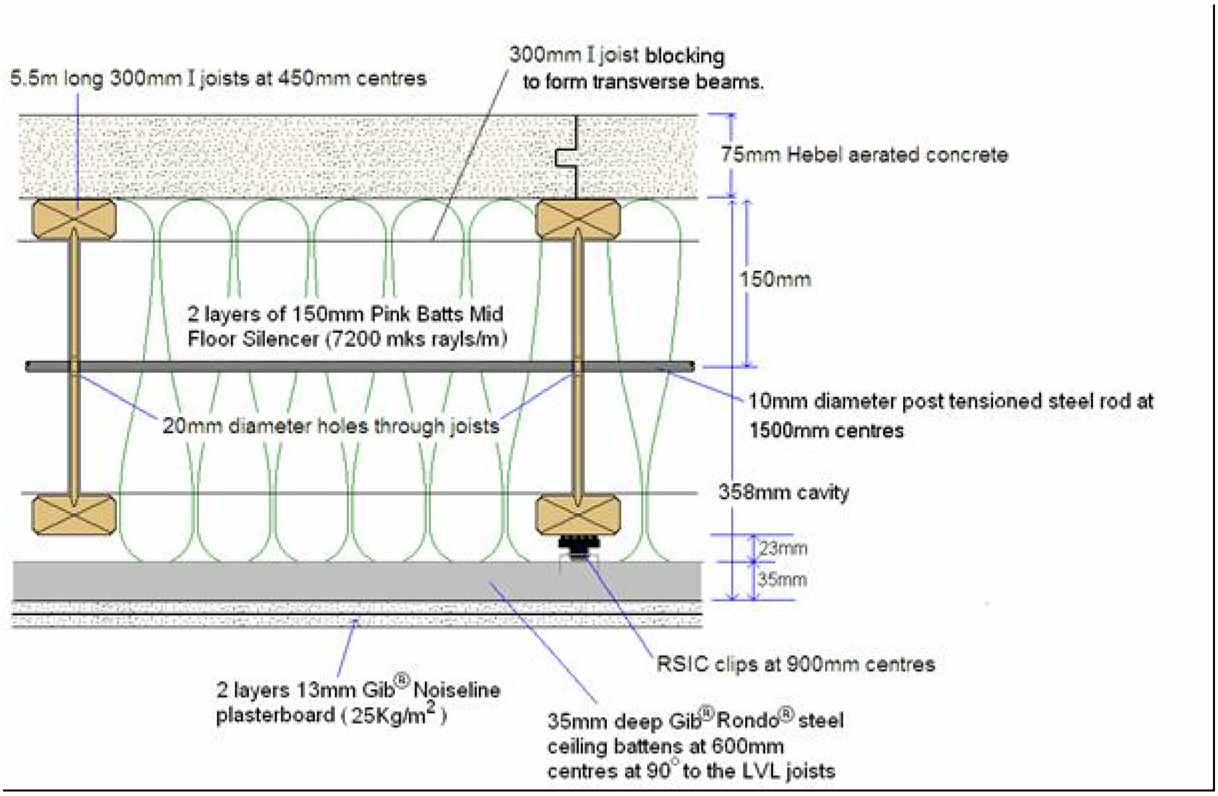

Figure 4. Aerated concrete topped floor.

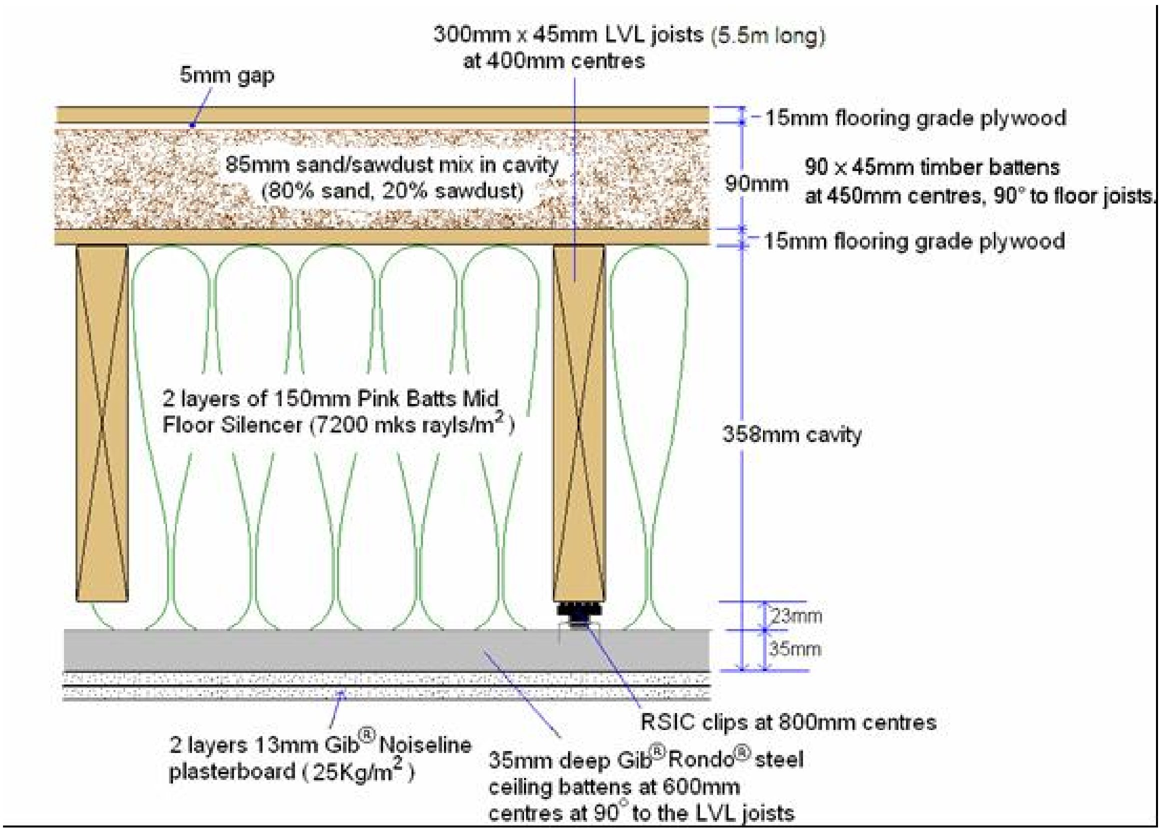

Figure 5. Sand-filled floor.

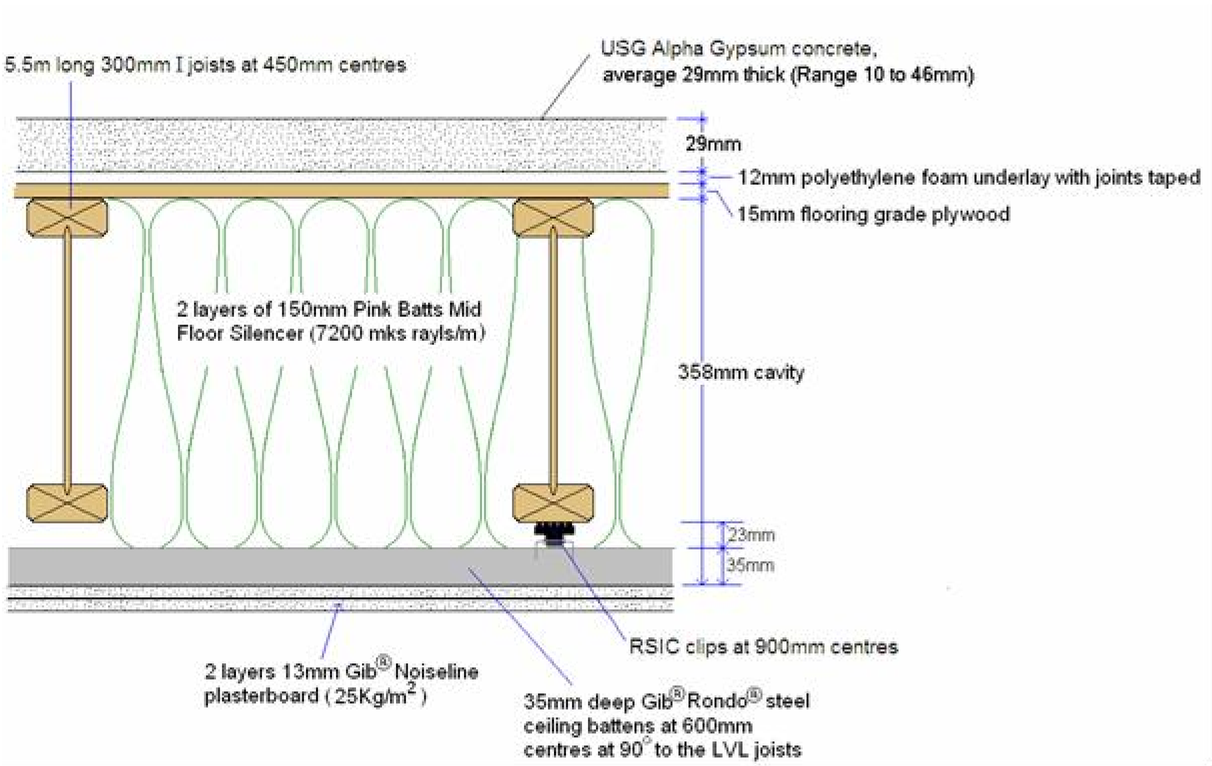

Figure 6. Floating Gypsum concrete topped floor.

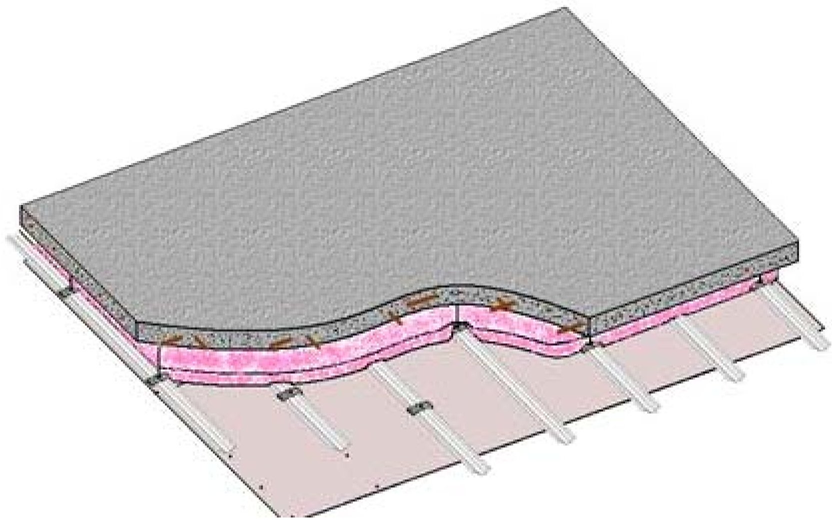

Figure 7. 150mm concrete slab floor with ceiling. Ceiling consists of 1 layer of plasterboard attached to concrete through RSIC clips, with 100mm of fibreglass batts in cavity.

One way to rate low-frequency impact sound performance is to have someone walk on the floor and assess the sound generated by these footsteps in the room below the floor. Subjective testing showed that a good measure of low-frequency performance was loudness of the footsteps, and a suitable measure of loudness was $L_{A,Eq}$. Table 1 shows the results for the floors considered.

Description	Estimated elemental cost in Sydney per square metre in A$	Estimated Footstep Sound Level below 200Hz - $L_{A,Eq}$ (dB)	Depth of Floor in mm
Basic, timber-framed intertenancy floor	250	35	399
Gypsum-fibreboard topped floor	346	31	437
Aerated concrete topped floor	290	30	459
Sand-filled floor	314	24	504
Floating Gypsum concrete topped floor	293	24	440
150mm Concrete Floor with suspended ceiling	260	26	393

Table 1. Acoustic performance of the floors as determined by the sound level produced by footsteps on the floor, and measured in the room below the floor. A smaller sound level is better. The depth of the floors and estimated cost to build the floors in Sydney is also shown.

We can see from the low-frequency impact insulation results that the sand-filled floor and the floating gypsum concrete floor perform similarly to the 150mm concrete slab floor. The sand-filled floor, however, has become quite deep and somewhat more expensive, which makes it less desirable than the floor with the floating gypsum concrete screed. Other the other hand, the floating gypsum concrete screed is less easily built than the sand-filled floor because it requires another subtrade which is not commonly available in New Zealand and Australia, and although it sets within hours, it needs time to dry out properly (often weeks). Having said this, such gypsum concrete screeds are common in the USA and Canada, and so could be imported into Australasia with relative ease. In fact, one large, USA-based manufacturer of such gypsum concrete screeds (Maxxon) is currently seeking to penetrate the Australasian market, and is training installers in key cities.

LCA COMPARISON

The floors were compared with regard to their primary energy use and the emission of green house gases.
The primary energy use takes all energy for the manufacture of the materials into account. For timber for example this includes forest management, harvesting operations, transport to the sawmill, sawmilling etc. This is often referred to as embodied energy, but is better described as ‘cumulative energy demand’. In this case only energy from non-renewable sources has been taken into account.

Green house gas emissions for all stages of the life cycle are also taken into account. The uptake of carbon during the growth of the timber has been taken into account, but the same amount is considered to be emitted at the end of life due to decay of the timber. This aspect of the timber is therefore regarded as carbon neutral. All emissions from harvesting and transport processes are taken into account. The life cycle data is based on a consistent LCA database (PE –Europe) and is modelled in the LCA software GaBi 4.2.

The comparison has been done on a basis of 1 m^2 of flooring (functional unit). It should be noted that the thermal properties of the floor types might be different. The subsequent differences in heat losses and heating requirements have not been taken into account. This might be necessary for a holistic comparison, although in general, we would expect intertenancy floors to have no net heat loss if the tenancies are at similar temperatures. As noted above for the economic assessment, the choice of the floor type can also influence other aspects, such as the required foundation and wall systems. Such a ‘whole building approach’ is not done in this study, and it is important to note that one really needs to consider the whole building when drawing a complete comparison between completely different construction systems (e.g. concrete versus timber-framed). However, when comparing like construction systems, such as timber-framed systems, a functional unit comparison is valid, since we would not expect the other aspects of the building design to change significantly.

The same transport distance has been assumed for all materials. It is important to take the transport into account, due to the significant differences in weight that needs to be transported to the building site. The concrete floor for example has a mass of 367 kg, whereas the basic timber-framed floor only weighs 59 kg.

200 g of rubber are required for each flooring system and has been left out, because no adequate dataset for this was available in the LCA database. Since this is the same for all floors, this omission is justified.

Table 2 shows the results of the LCA performed on the floors. We can see that, of the timber-framed floors, the floating gypsum concrete floor performs particularly well.

Description	Estimated elemental cost in Sydney per square metre in A$	Depth of Floor in mm	Global Warming Potential (kg CO_2 equivalent) per m^2 of floor	Embodied Energy (MJ per m2 of floor)
Basic, timber-framed intertenancy floor	250	399	50	489
Gypsum-fibreboard topped floor	346	437	59	643
Aerated concrete topped floor	290	459	53	515
Sand-filled floor	314	504	61	566
Floating Gypsum concrete topped floor	293	440	41	471
150mm Concrete Floor with suspended ceiling	260	393	53	423

Table 2. Life-cycle assessment results of floors.

Examining the key contributions to the energy demand and CO_2 emissions and improving environmental performance

From the above acoustic and life-cycle assessments we can see that the floating gypsum concrete topped floor performs well in comparison to the other floors. It may well pay to see if we can improve the environmental performance of this particular floor without compromising the acoustic performance. To do so, we can focus in on the life-cycle assessments by examining a breakdown of the contributions of various components of the floor. Table 3 shows such a breakdown for the floating gypsum concrete topped floor.

Floating Gypsum Concrete Floor Components	MJ (% of total)	kg CO_2-Equiv. (% of total)
Transport	1.8	1.5
Fibreglass	38.6	30.7
Glued laminated timber	16.2	25.7
Gypsum board	16.8	13.2
Gypsum plaster	3.9	3.0
Plywood board (5% humidity)	12.5	21.5
Polyethylene low density	8.3	2.8
Sand (grain size 0/2)	0.3	0.3
Steel sheet galvanized	1.5	1.3

Table 3. LCA component breakdown of the floor with floating gypsum concrete (Cumulative energy demand and CO2 equivalent emissions).

Clearly from Table 3 we see that the fibreglass and the engineered wood products are major contributors to overall green house gas emissions and cumulative energy demand. We could change the I-beam joists to kiln-dried solid wood joists, but we would need solid wood joists 2 or 3 times as heavy to get the same structural performance, and we would face resistance from builders who prefer the easier construction techniques possible with the wooden I-beams. The fibreglass is present in the floor to improve acoustic performance. However, it is not essential to use a lot of fibreglass, or indeed we can substitute fibreglass for another fibrous material such as rock wool or macerated paper. Table 4 shows the various fibrous infill options which are expected to not change the acoustic performance significantly with the cumulative energy demand and CO_2 equiv. emissions for the whole floor.

Changed parameters	Total floor LCA results	
Acoustic Infill Options for Gypsum Concrete Floor	MJ	kg CO2-Equiv.
300mm (4.5 kg/m^2) of acoustic type fibreglass	471	41
100mm (1.5 kg/m^2) of acoustic type fibreglass	350	33
4.5 kg/m^2 of rock wool	352	34
4.5 kg/m^2 of macerated paper infill	351	30

Table 4. Cumulative energy demand and CO_2 equiv. emissions for the floating gypsum concrete floor with various infill options. The different infill options should not significantly affect the acoustic performance.

CONCLUSION

Previous research into improving the sound insulating performance of timber-framed floors has been extended by performing stream-lined environmental life cycle assessments on a number of the floor designs. A timber-framed floor with a floating gypsum concrete screed performed well in terms of its sound insulating ability, its cost to build, and its overall environmental life cycle indicators. The life cycle indicators of this floor were broken down into component contributions to see whether its environmental impact could be reduced without reducing the acoustic performance. It was found that the fibrous infill in the floors contributed greatly to the environmental life cycle indicators, but did not significantly alter the acoustic performance.

It is therefore clear from this work that there is potential to significantly reduce the environmental impact of a building system without compromising other performance criteria, if designers are made aware of the environmental impact of each component of the system. The case study has shown that a combination of performance based indicators and a life cycle assessment approach in combination are practical way for designers to improve the design of building components.

Further research, including a full environmental and economic assessment which takes into account different requirements for foundations, would be recommended.

REFERENCES

Blazier, W.E, DuPree, R. B. (1994). “Investigation of low-frequency footfall noise in wood-frame, multifamily building construction”, *The Journal of the Acoustical Society of America*, 96(3), 521-1532

Emms, G., Chung, H., Dodd, G., McGunnigle, K., Schimd, G., 2006. Maximising impact sound resistance of timber framed floor/ceiling systems, Forest and Wood Products Research and Development Corporation (Australia), Project PN04.2005.

Hveem, S. (1998). "Comparison of low frequency impact sound insulation of different Nordic lightweight floor constructions", *Proceedings of Acoustic Performance of Medium-rise Timber Buildings*, Dublin, Ireland, Dec. 1998.

GaBi: LBP, PE: GaBi 4. Software-System and Databases for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen