Sound Insulation of Timber Framed Structures

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Abstract

In many countries that have historically had good forestry resources (Scandinavia, Scotland, Canada, North America, New Zealand), smaller buildings have been built with a timber frame that is then lined externally and internally to provide walls, floors and ceilings. The sound insulation and impact insulation properties of these timber framed buildings is significantly different to buildings constructed from monolithic materials (stone, brick, concrete). With the increasing use of timber framed construction for multi-unit dwellings, the sound insulation of such constructions is assuming greater importance.

Introduction

Timber framed buildings are widely used throughout the world and are an economical and flexible method of construction. Their advantages include quick and easy construction with no wet trades to delay progress, good resistance to earthquakes, cheapness, flexibility to alter or extend, lightweight (making foundation requirements less) and only requiring simple infrastructure and construction skills to build.

Simple methods of timber construction only provide modest sound insulation against airborne and impact noise, however, many methods have been developed to achieve high levels of sound insulation. This paper will discuss the development of timber framed constructions for sound insulation, the principles for achieving good insulation and illustrate some examples of modern techniques.

Sound Transmission Principles

The mass law, which relates the sound transmission of a wall to its mass, is one of the oldest and simplest relationships in acoustics. Put simply, it says that the sound transmission of a wall is proportional to its mass per unit area, increasing by 6dB per doubling of area and 6dB per doubling of frequency. However, in the early days of acoustics it was found that certain constructions could out perform the mass law. Figure 1, which is taken from Harris' Handbook of Noise Control [1], is a good example which shows that cavity constructions can have transmission losses 5 to 10 dB higher than an equivalent weight solid wall. Because timber framed construction are inherently cavity constructions it is important to understand the basic behaviour of cavity constructions to be able to develop high performance timber frame constructions.

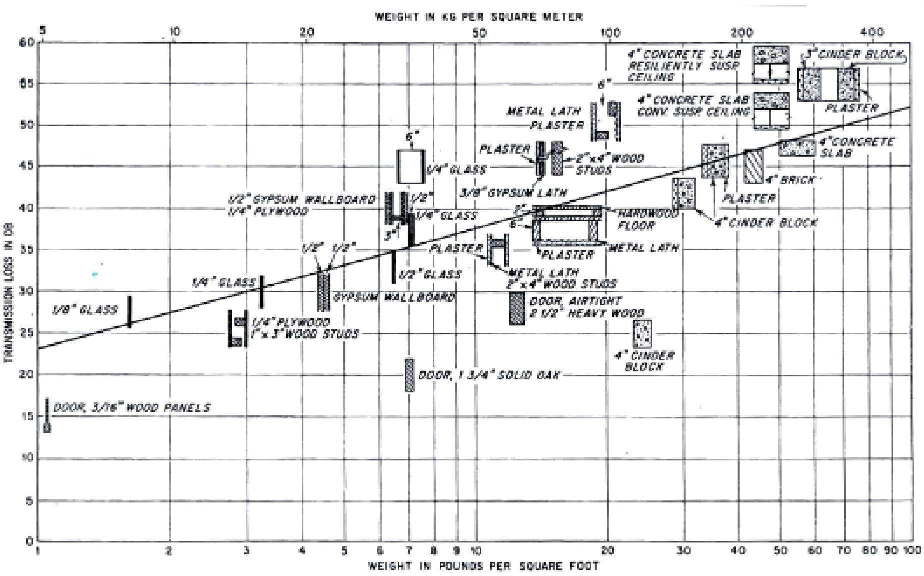

Figure 1: The Mass Law

Single Panel

Typically a timber frame will be lined on both sides with a thin sheet material to provide the interior or exterior surfaces of the building. In most internal situations the thin panel will be gypsum board 6 mm to 16 mm thick. Thin panels can be modelled for most acoustic purposes by a mass per unit area *m* and a bending stiffness *B*. At low frequencies the transmission loss is low, increasing by 6 dB per octave. At high frequencies the transmission loss dips to a minimum at the critical frequency, increasing by 12 dB per octave above that frequency. The transmission loss at low frequencies is given by

$$R = 20\,Log\,(mf\,) - 48 \qquad (1)$$

and at high frequencies by

$$R = 20Log(mf) - 48 \qquad (2)$$
$$-10Log(2\eta\omega / \pi\omega c)$$

where the critical frequency *fc* is given by

$$f_c = \frac{c^2}{2\pi}\sqrt{m/B}$$

These simple equations describe single panel performance remarkably well over a wide range of materials and sizes, although isotropic or very thick panels need additional consideration.

Double Panels

When a wall is formed by covering both sides of a timber frame with thin panels (such as gypsum board) then the sound transmission becomes considerably more complex. The ideal case of two panels isolated from each other with the air cavity filled with a highly porous sound absorber will be considered first, although transmission through the frame will be shown to be very important. The ideal case can be approached quite closely by double stud walls with a fibreglass or polyester blanket in the cavity.

A simple view of the transmission can be obtained by dividing the frequency range into three regions. At low frequencies the stiffness of the air cavity is so large that the two panels are effectively locked together and act as a single panel of the combined mass. The transmission loss is simply given by the mass law using the combined mass m_1, m_2 (but ignoring the mass of the frame).

$$R = 20\,Log\,\left(f\,(m_1 + m_2)\right) - 48 \qquad (4)$$

This applies up to the so called mass-air-mass resonant frequency of the system. Note that the resonant frequency of the system will depend on the presence or absence of a sound absorber in the cavity and the width of the cavity *d*. With a sound absorber in the cavity, compression of the air becomes isothermal and the speed of sound is lowered to around 290 m/s, thus lowering the resonant frequency by about 9%.

Above the mass-air-mass resonance the transmission loss increases at

18 dB per octave and is given by [2]

$$R = R_1 + R_2 + 20\,Log\,(\,fd\,) - 29 \quad (5)$$

This is a reasonable approximation up to a frequency at which the width of the cavity is equal to 1/6 of the wavelength. Above this frequency the transmission loss increases at a more modest 12 dB per octave and is given by

$$R = R_1 + R_2 + 6 \quad (6)$$

An illustration of the validity of these simple relationships is given in Fig 2 for a double stud construction lined on each side with 2 layers of 10 mm thick gypsum plasterboard, with a 100 mm fibreglass blanket in the cavity. For most engineering purposes this agreement can be taken as excellent.

Connections

In simpler constructions there is no separation between the panels on either side of the wall. A basic single stud wall has vertical timber studs at 600 mm intervals, often with nogs or horizontal pieces of wood at 800 mm intervals.

The linings are then fixed with nails, screws or glue at approximately 150 mm intervals around the perimeter of sheets of plasterboard, with fixings at 300 mm in the middle of the sheet.

This construction can be modelled as separate sheets with line connections at interval *b* between the panels [2]. The vibration of the panel on the source side of the wall is transmitted directly to the panel on the receive side.

In addition to the sound transmission due to ideal double panel behaviour, there is now sound radiated from the near field due to this forced vibration. This can be calculated and added to the transmission already calculated from (2) – (6).

$$R = R_{1+2} + 10\,Log\,(b.f_c) + 20\,Log\,[m_1 / (m_1 + m_2)] - 18 \quad (7)$$

The interesting implications of this model are that the transmission increases with the number of connections (which is intuitively obvious) but also increases as the critical frequency of both panels is reduced. Thus the stiffer the panel the more serious the degradation due to the transmission due to the frame. An illustration of the performance of single framed partitions is shown in Figure 3.

In Figure 3 it can be seen that the measured results exceed the results predicted for line connection above 400 Hz.

The explanation for this is considered to lie in the behaviour of the connections between plasterboard and stud.

In Figure 4 the relative velocity of the screw compared to a point on the plasterboard lying along the stud but halfway between screw fixings are shown. If there was a true line connection then the velocity should be same all along the line of the stud, but it can be seen that at frequencies above about 250 Hz the plasterboard between the screw fixings is moving

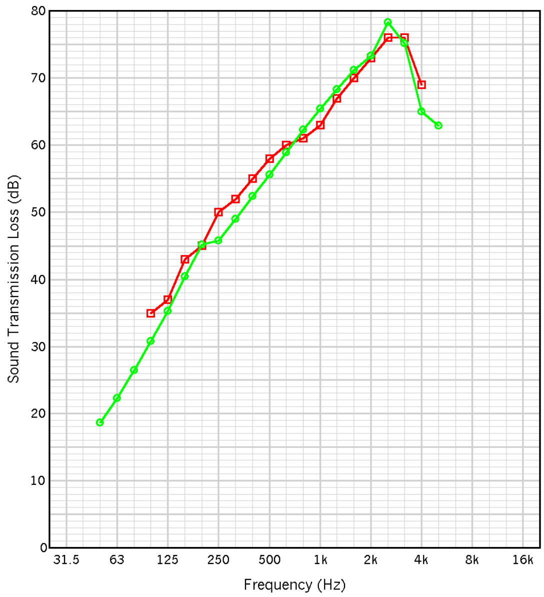

Fig 2 Double frame wall with 2x10mm gypsum board on each side

measured
predicted for ideal double wall

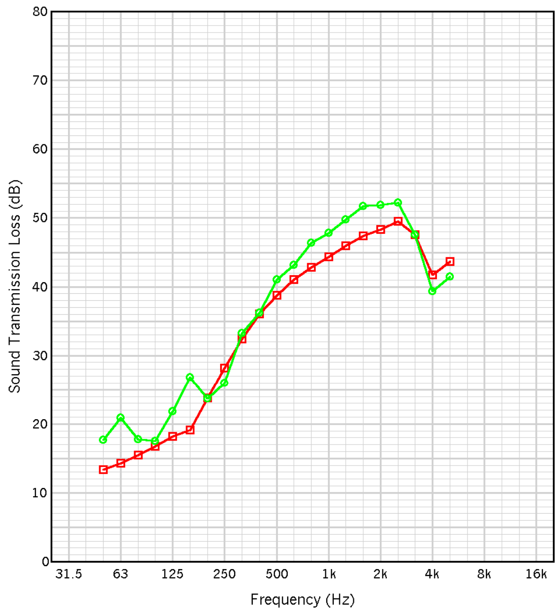

Fig. 3 Single frame wall width 10mm gypsum board on 90 x 35 mm frame with studs at 600mm centres

measured
predicted for line connections at 600mm

much less, interestingly above 2,500 Hz the connection appears to move as a line connection again. Between 250 Hz and 2,500 Hz the connections act more like point connections.

As has been shown the ideal case of no connections can be approached by using a double stud connection. However, this is not always possible and various methods of isolating linings have been developed, such as staggered studs, resilient rails and more recently resilient clips. The performance of such components can be predicted if the stiffness or compliance of the isolator is known [3].

Some Developments in Timber Framed Walls and Ceilings

Early walls were simple timber frames with various types of lining on each side. In early New Zealand houses built from around 1850 to 1920 the linings were commonly wooden sarking, (thin timber about 10 mm thick) fixed horizontally with large gaps between boards, with hessian scrim stretched tightly in front of the sarking, with wallpaper glued to the scrim.

While I have no data for this type of construction, it must have been very poor because of the numerous gaps in the sarking.

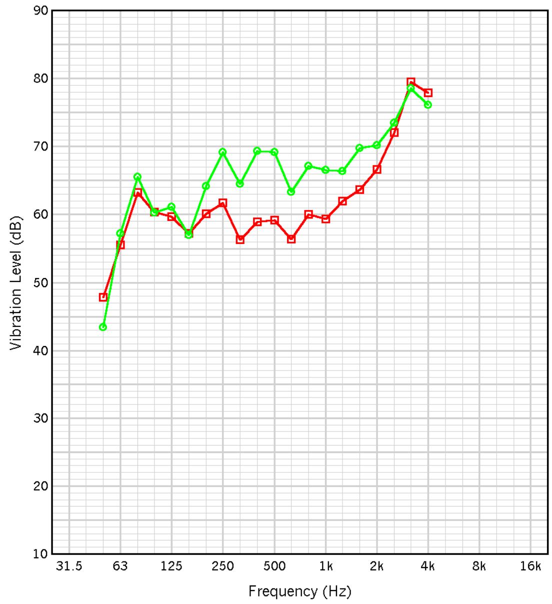

Fig. 4 Vibration measured on gypsum board on stud line for single stud wall

measured on screw
measured between screws

Another early type of lining was a lath with lime or gypsum plaster of about 12 – 13 mm thickness on top. This type of construction could achieve R_w 30 – 35 [4]. A method of improving on this was to fix 50 x 50 mm timber strips to the bottom and top of the wall and fasten 12 mm wood fibre board to these to maintain a 50 mm airgap to the original wall, with 12 mm of gypsum plaster on top of the fibreboard.

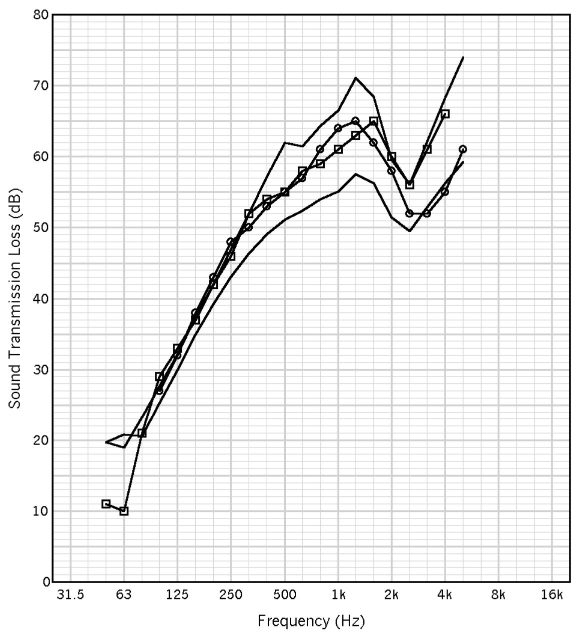

Fig. 5 Performance of resilient fastenings 16mm plaster board on 100x50 studs

Rubber Isolation Clip
Quietzone studs
ideal double wall
resilient rail

This achieved R_w 45 - 50. An early method to reduce the connection provided by the studs was to place a saw cut in nearly the whole length of the stud. With 13 mm plasterboard both sides and a fibreglass blanket in the cavity the sound insulation could be improved from about R_w 39 to R_w 43.

A more successful development was obtained using staggered studs in which a wider top and bottom plate was used, together with two rows of studs, one row off set to one edge of the top and bottom plates and the other row off set to the other edge of the plates. With 13 mm plasterboard and 100 x 50 studs on 150 x 50 top and bottom plates a rating of about R_w 48 could be achieved.

Both split stud and staggered stud designs were limited by the transmission through the common top and bottom plate which still provide a solid connection between the linings. The staggered stud design also used twice as many studs as a simple stud wall.

In the early 1960's various resilient devices were developed to attach to a simple single stud wall to isolate the linings on one side. The most successful turned out to be the resilient rail, which in various forms is still widely used today. With this, a similar performance to a staggered stud wall could be obtained but with half the quantity of timber and a 40 mm thinner wall. In America this rail was also widely used to attach ceiling linings. It has, however, been found that resilient rail walls (at least in New Zealand) are very vulnerable to faulty installation and the field performance is usually more than 5 dB or more below its laboratory rating.

Two recent developments promise to provide the required isolation more reliably. One is the so called "acoustic stud", which has been developed by Owens Corning in America. This provides a factory built stud that has a timber load bearing part, with another thinner non load bearing timber batten fixed by resilient metal brackets. This has performance somewhere between a resilient rail and an ideal separate stud.

Another recent development is a resilient rubber or neoprene isolation clip that fixes to the timber stud and carries a metal rail to which the second lining is fixed. The design of the clip makes it less susceptible to faulty installation, and performance is similar to the "acoustic stud" being somewhere between a resilient rail and ideal separate stud performance.

In most ways ceilings are just floors turned sideways, however, gravity does affect some practicalities. A ceiling in which the floor linings and ceiling linings are directly fixed to the floor joists performs just as a single stud wall does, with direct transmission via the timber structure limiting performance to modest levels.

Typically a construction with a plywood or particle board floor and a gypsum plaster ceiling directly fixed would have a sound transmission of R_w 35 - 40. Resilient rails can be used to increase this to about R_w 45 - 50. Rubber isolators can also be used for this situation to achieve an improvement to R_w 50 - 55.

Some Practical Considerations

It is well known that small gaps in walls can lead to significant reductions in sound transmission loss and timber frame walls can be affected by poor sealing. However, they are in some respects less prone to drastic failure than monolithic walls.

The most critical point for sealing is the perimeter where a gap under a plate permits transmission directly from the source to receiver room. However, gaps in one lining alone often do not cause a significant loss of performance.

Tests have for instance shown that electrical fittings in a high performance wall do not seriously degrade the wall, provided that

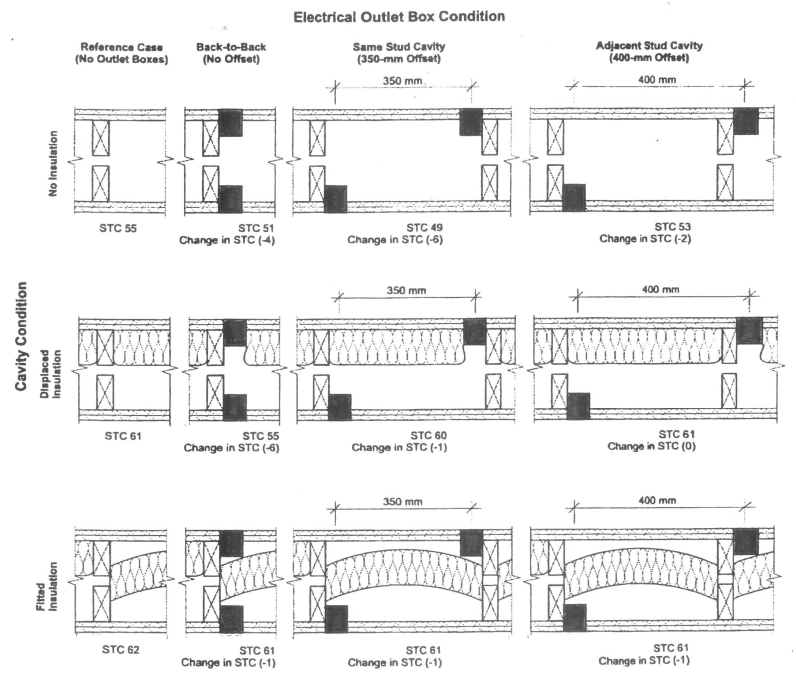

Fig 6 Reduction in sound insulation due to electrical fittings

some simple precautions are taken [5] (see Fig. 6).

A common occurrence in the building industry is substitution of components with generic equivalents. This can have serious effects when dealing with acoustic components. An example of this is in a 4 level timber framed building in which the ceilings were to be fixed by using a steel batten. The design that had been tested and achieved R_w 55 used a light W shaped batten held in a steel clip. However, manufacturer's details only referred to the component as a "steel batten". The contractor installing the ceilings used another manufacturers steel batten that was a heavier gauge of steel, and a more rigid "top hat" section.

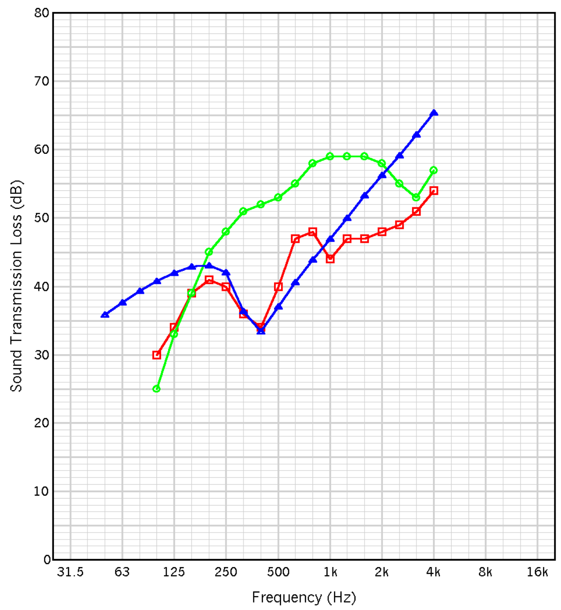

Fig 7 Predicted flanking transmission for 32mm thick timber floor

measured transmission with flanking
Transmission loss of wall
predicted flanking transmission

The result was to introduce a serious reduction in performance due to the resonant frequency of the ceiling and batten being raised above 100 Hz, thus reducing the sound transmission loss to R_w 42. Similar effects have been observed with a resilient rail, which was copied by a manufacturer unaware of the subtleties of the original design.

Flanking Transmission

While the transmission of sound through timber framed walls and ceilings is comparatively well understood and partitions of high performance can be designed and built, in a complete timber framed building sound can travel through flanking paths to cause significant loss of expected performance.

A simple model of flanking through timber structures [6] gives the following relationship

$$R_f = R_c - 10\log(\sigma) + joint\,loss - 10Log(A/A_c) \qquad (8)$$

This relationship shows the principle factors that influence flanking transmission.

Firstly, the sound transmission loss *Rc* is the transmission loss of the common lining, which is usually plasterboard or a flooring membrane such as plywood or particle board. This element is typically R_w 30 - 35 dB.

The radiation efficiency factor can add about 5 dB, the joint loss of typical + joints is about +10 dB and the area factor contributes about +5 dB. Thus typically the flanking path will be about R_w 50 - 55 dB, which will limit the performance obtainable from high performance partitions. However in some situations it can be significantly worse.

A particularly severe example of flanking limiting performance was found in a heritage wooden building with 35 mm thick hardwood floors on top of which apartments were built, with the floor running underneath the inter tenancy partition. The timber floor had a rather low critical frequency because of the high stiffness and light weight of the timber floor.

The result was that the radiation efficiency was close to 1 over much of the range, with a coincidence dip at a low frequency. The predicted and measured flanking transmission is shown in Figure 7.

The flanking path was predicted to be R_w 44 dB and measured as R_w 42 dB, whereas the inter tenancy partition was designed to achieve R_w 58 dB. In this situation the direction in which the joists ran is significant for determining the area in the receiving room which radiates flanking sound.

If the joists run parallel to the partition then the structure borne sound is quickly attenuated and only one or two joist widths will contribute significantly to flanking radiation. Measurements made on a timber framed wall show that structure borne vibration is attenuated strongly when it flows at right angles to the stud or joist, but is not attenuated when it travels parallel with the stud or joist.

Impact Sound

Impact sound is of great interest when timber construction is used for residential buildings. The lightness and flexibility that are attractive qualities to an architect or engineer lead to rather high levels of impact sound being created by activities such as walking around.

Relatively little research has been carried out on the problem, but it is often seen as one of the main draw backs in using timber framed buildings for apartments and multi-unit dwellings. With concrete floors impact sound is primarily a high frequency problem and can be relatively mitigated by either using a soft floor covering or by using a soft underlay under a hard floor covering.

With timber floors, however, footfalls generate substantial low frequency vibration, which can couple rather well into normal sized domestic rooms. The frequencies of concern can often be below the traditional frequency range for rating methods such as IIC or Ln and so floors can apparently meet specification while still being unacceptable to residents.

A well known example concerned a set of condominiums in America, which while achieving IIC 55 became the subject of a major law suit for unsatisfactory performance [7].

The conclusion of the study on this project was "*...at present, there is no economically practical method of*

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avoiding the perception of "thuds" and "thumps" in rooms beneath the walking surface." Since that time there have been studies undertaken in Scandinavia and lately New Zealand to find practical solutions to the low frequency problem.

Summary

There are many different factors involved in achieving good sound insulation in timber framed structures such as isolating wall or ceiling linings, achieving high critical frequencies for linings, filling cavities with sound absorption, achieving an adequate combination of mass and air cavity depth, and making structural discontinuities between rooms.

The current state of knowledge enables the accurate design and construction of floor and walls to achieve good sound insulation, suitable for average quality residential requirements. With special precautions involving special structural design it is possible to achieve excellent sound insulation performance, but impact insulation may still be marginal, and low frequency sound insulation may not be as good as solid masonry construction.

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