inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 5.1

FAILURES IN SOUND INSULATION OF TIMBER BUILDINGS

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Keywords:
TIMBER STRUCTURES, TIMBER FRAME BUILDINGS, LIGHT-WEIGHT STRUCTURES, FAILURES

ABSTRACT
Sound insulation results from recent research and development projects concerning light-weight timber constructions have shown that acceptable sound insulation level can be achieved in timber frame buildings. However, the first timber frame buildings in Europe have been designed in close co-operation with researchers and built under most careful supervision. Nowadays the most structural engineers and contractors still do not have enough information on sound insulation properties of timber structures. Therefore, there is a risk of sound insulation failures. Sound insulation of timber buildings depends sensitively on failures in workmanship and structural design. Fortunately, these failures are easy to avoid by careful design of structural details and connections and supervision on the site.

1 - INTRODUCTION

Multi-storey timber buildings have been studied and developed in many European countries during the last decade. The main interest in these studies has been timber joist floor which has had quite weak impact sound insulation at low frequency range below 100 Hz. Results of the research and development projects have been successful in e.g. some projects carried on in the Nordic countries. Some measurement data of impact sound insulation is shown in table 1. These result show that acceptable sound insulation level can be achieved in timber apartment buildings [1-2].

Location	Bearing floor construction	$L'_{n,w}$	$L'_{n,w}+C_{I,50-2500}$
Ylöjärvi, Finland	Ribbed slab of laminated veneer lumber	40 dB	48 dB
Oulu, Finland	Composite construction of concrete slab and timber joists	44 dB	51 dB
Linköping, Sweden	Thin web I-beams	49 dB	51 dB
Växjö, Sweden	Timber joists	51 dB	54 dB
Hørsholm, Denmark	Timber joists	50 dB	52 dB

Table 1: Impact sound pressure levels (dB) of some timber buildings in the Nordic countries.

The first modern timber frame buildings in Europe have been designed in close co-operation with researchers and built under most careful supervision. Nowadays the most structural engineers and contractors do not have enough information on sound insulation properties of timber structures. The intention of the structural engineers is usually good, but the field of acoustics and sound insulation is often difficult for them. There is still not many design and construction handbooks dealing with sound insulation of timber buildings. The lack of knowledge concerns also inspection authorities. Therefore, there is a risk of sound insulation failures.

Sound insulation of timber structures depends sensitively on careful structural design and supervised construction. Some of the following examples are results of intentional experiments, which are also reported in references. Many of the examples are, however, real failures which have been noticed in sound insulation measurements on the site. Some of these measurements are not published before.

2 - FLOATING FLOORS

Acceptable sound insulation in the first timber frame buildings has been achieved by using floating floor and resilient hinged ceiling in floor structure. However, the costs of floor structure are usually high in comparison with other structures of timber buildings. The costs depend partly on materials and work. According to the contractors, installing the floating floor delays the progress of other inner works. This leads often to demands of decreasing the amount of structural layers of the floor. This would cause problems in exceeding the sound insulation criteria.

In a research reported in reference [3], the effect of floating floor and resilient hinged ceiling was studied in a full-scale test building. Same floor structure was measured with and without resilient structures. Table 2 shows that impact sound insulation of timber joist floor depends significantly on them: in both cases impact sound pressure level weakened at least 10 dB. If contractors want to reduce costs of timber joist floor, they should carry out a study in which a new timber floor could be developed. Some results have already been presented in reference [4].

Structure	$L'_{n,w}$	$C_{I,50-2500}$
With floating floor	48 dB	5 dB
Without floating floor	58 dB	0 dB
With resilient hinged ceiling	46 dB	6 dB
Without resilient hinged ceiling	57 dB	4 dB

Table 2: Dependence of impact sound insulation on floating floor and resilient hinged ceiling.

Problems with impact sound insulation may occur even when there is a functioning floor structure in the apartments. Balconies and corridors are often supported directly from the bearing structures of the building or floor joists act as cantilever beams which form the bearing floor structure of the balcony. In such cases residents of apartments in lower storeys may be disturbed by impact sounds produced by walking on the balcony. For example, in one of the Finnish timber frame buildings of table 1, impact sound pressure levels measured from the balconies to apartments were from 60 dB to 64 dB. Therefore, better solution is that balconies have own bearing structures which are separated from bearing walls and floors of the building. Otherwise, the balconies should also have floating floors or other damping layer.

It is often easy to install different HVAC-pipes in the resilient layer. In such cases, some complaints concerning sound insulation has occurred. When the diameter of the pipes has been nearly as thick as the resilient layer, the surface plate of floating floor has had connections with bearing structure. To reduce the sinking of the floating surface, timber sections have been placed in the near of the pipes. These solutions have affected negatively to impact sound insulation.

3 - STRUCTURAL DESIGN AND WORKMANSHIP

Sometimes contractors pay more attention to sound insulation than usually. In such cases, buildings are also often marketed as "quiet buildings". However, these quiet buildings may become noisy because of even little mistakes in structural design and workmanship. These failures may depend on insufficient theoretical knowledge of structural engineer or failures carried out during construction.

A terraced house was built of box elements. This construction method provides good possibilities to high sound insulation level, while structures of each apartment can be separated from structures of other apartments. Structural engineer of the case building also intended to take this advantage of the construction. In building plans is shown that there is no connections between adjacent apartments. Roof and floor structures are both cut at the edges of the apartments.

Despite of the good intention of structural engineer, the first complaints dealing with poor sound insulation came during the same day when inhabitants moved in. It was noticed that double wall between apartments had been covered by plasterboards on both sides of wall studs. This was beneficial to horizontal stability of the building and fire protection of wall studs. Thus, sound insulation at low frequency range was very poor because of several resonance frequencies. However, building official accepted the original building plan without remarks as like as contractor.

Failures in workmanship during construction lead often to problems with flanking transmission. Acceptable sound insulation in timber buildings usually requires that there is no connections between structures of adjacent apartments. The significance of HVAC-installations has also to be remembered. For example, improperly assembled sound absorbers of ventilation channels may reduce apparent sound reduction index R'_w even 15 dB [3]. To ensure acceptable sound insulation, HVAC-pipes should have connections only with bearing frame structures and they should be separated from surface structures of walls and floors as completely as possible.

4 - BUILDING CODES

Some sound insulation failures cannot be avoided by careful structural design and construction. Usually, a structural engineer may trust on building codes, but sometimes there is situations, when building codes have not been taken everything into account. They may even lead to unsatisfactory structures and design. These situations are problematic, while the most of structural engineers do not have such background information which could help them to recognise these questionable parts of the building codes.

The new European building code of timber structures, Eurocode 5, demands that vibration of floor should not cause unacceptable discomfort to the users. A design method is also presented for residential floors with fundamental frequency greater than 8 Hz. This fundamental frequency limitation is based on vibrations produced by walking. Unfortunately, the spinning speed of washing machines is nowadays not less than 400 rpm i.e. 7 Hz. Therefore, washing machines may cause temporary vibration and noise problems. Noise levels from 47 to 52 dB(A) were measured in an apartment below another apartment where a washing machine was spinning on a timber floor with span of 5 m and fundamental frequency of 18 Hz. Vibration problems can be avoided by e.g. using concrete slab element in bathrooms or other rooms where washing machines are placed.

Sound insulation requirements in the most of the European countries are based on ISO standards. Researchers have known since the 1960's that impact sound pressure level $L'_{n,w}$ does not correlate well with inhabitants' subjective opinions on sound insulation of timber structures [5-6]. Therefore, in the new revised versions of ISO standards, spectrum adaptation term $C_{I,50-2500}$ was introduced. The purpose of the spectrum adaptation term is to take the problematic low frequency range below 100 Hz into account. However, e.g. the new Finnish building code published in the beginning of the year 2000 does not require the use of spectrum adaptation term. If low frequencies are not taken into account, structural engineer may choose also a floor structure which is in fact unacceptable.

5 - CONCLUSIONS

Structures which produce acceptable sound insulation in timber buildings have been developed during the last decade. Therefore, problems with sound insulation depend nowadays mainly on failures in structural design and workmanship. If timber constructions, especially multi-storey timber apartment buildings, become popular, education of structural engineers and contractors is needed to avoid these failures. Design and construction manuals should also be published. In the Nordic countries, one design manual has already been published [7]. In timber construction, attention should also be paid to careful supervision on the site.

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