CHAPTER 5
OVERVIEW OF RESEARCH ACTIVITIES AT THE MAIN INSTITUTES MEMBERS OF COST FP0702

COST Action FP0702

Net-Acoustics for Timber based Lightweight Buildings and Elements

CONTENTS

In order for the reader of this e-book to have a better idea about the research activities on timber based lightweight buildings at the main institutes participating in COST Action FP0702, an "overview of research" document has been created giving the current (and previous) research topics and the associated available papers and presentations.

The following institutes (in order of presentation) have given information on their research activities:

- **TNO, The Netherlands**
- **Lulea University of Technology, Sweden**
- **Liverpool University, UK**
- **CSTB, France**
- **Hochschule Rosenheim, Germany**
- **PTB, Germany**
- **Holzforschung, Austria (HFA) in cooperation with Technical University, Vienna, Austria**
- **TECNALIA Spain**
- **BBRI, Belgium**
- **SINTEF, Norway**
- **University of Canterbury, Christchurch New Zealand**
- **RMIT and CSIRO, Australia**
- **NTNU, Trondheim, Norway**
- **FCBA, France**
- **Center for Timber Engineering, Edinburgh Napier University, Scotland**

1 - RESEARCH ACTIVITIES AT TNO

Eddy Gerretsen, Susanne Bron-v.d.Jagt, Arnold Koopman, Sven Lentzen relevant for WG1 and partly WG2

1.1 - Current research

- research project with industry on characterising junctions of light weight building systems, also timber based, sound and vibration down to 0 Hz; measurements and modelling (FEM, SEA) of junctions and incorporation in total transmission model like EN12354; 2005-2010; reports only in Dutch, see papers on Acoustics'08 and others
- TNO-research project on understanding and solving problems in the combination of equipment sound and light weight buildings; 2007-ongoing; see Acoustics'08 paper, EN 12354-5
- TNO-research project on developing an analytical/numerical analysis tool for structural vibration and low-frequency noise ("Uil"); 2009-ongoing; no documents publicly available yet.
- TNO-research project on low frequency noise: perception, measurements en modeling; 2010-ongoing; see paper on Forum Acusticum '11.

1.2 - Previous research

- PhD-study on sound transmission through lightweight walls, Stefan Schoenwald; 2003-2008; see various papers and thesis
- ECSC research on vibrations Hivoss in which a European guideline (criteria, assessment methods) is written about walking-induced vibrations on floors and bridges; 2007-2008; see website
- various consultancy projects and/or trouble shooting on light weight building systems, both steel- and timber based; 1995 till now, both sound and vibration and, besides focusing on sound insulation, often focussing on walking induced vibrations (<20 Hz)

1.3 - Available papers / presentations

[1] G. Susanne Bron-van der Jagt, A. Koopman, C.C.J.M. Hak, *Sound transmission through cross-joints in multi-family houses with lightweight, double structures and steel supporting structures – measurements* -, Forum Acusticum 2002, Sevilla, september 2002 (paper and presentation)

[2] Koopman, W. van Gogh, G. Susanne Bron-van der Jagt, *Sound transmission through cross-joints in multi-family houses with lightweight, double structures and steel supporting structures – transmission models* -, Forum Acusticum 2002 – Sevilla, september 2002 (paper and presentation)

[3] Susanne Bron-van der Jagt e.a., *Sound transmission through junctions between lightweight floors and walls - comparison of FEM-, SEA- and measurement results*, Euronoise 2006, mei 2006 (paper and presentation)

[4] Gerretsen, E., *Possibilities to improve the modelling in EN 12354-1 for lightweight elements*, Euronoise, Tampere, 30 mei- 1 juni 2006

[5] Schoenwald, S. e.a., *Measurement of flanking transmission through gypsum board walls with a modified SEA method*, Internoise 2007, Istanbul, August 2007

[6] Gerretsen, E., *Some aspects to improve sound insulation prediction models for lightweight elements*, Internoise 2007, Istanbul, August 2007,

[7] HIVOSS documents, see www.stb.rwth-aachen.de/projekte/2007/HIVOSS/download.php

[8] Gerretsen, E., *Various acoustic aspects of buildings with lightweight elements*, CIB bijeenkomst W51, 216 mei 2008, Boras, Zweden

[9] Gerretsen, E., *Some practical aspects of the prediction of structure-borne sound caused by house-hold equipment*, Acoustics'08, Paris, 2008

[10] Gerretsen, E., *Prediction models for building performance – European need and world wide use*, Acoustics'08, Paris, 2008

[11] Gerretsen, E. *State of the art and future developments of the Eurpopean standard EN 12354,* AIA Building Acoustic conference, 11-12 March 2009, Ferrara

[12] Gerretsen, E., *The development of the EN 12354 series: 1989-2009*, Euronoise'09, Edinburgh, 2009

Abstract

The development of the building acoustic prediction models in EN 12354 started twenty years ago, since the CPD made it necessary within Europe to link the acoustic performance of building products and elements to the performance of buildings. It concerned six acoustic aspects: airborne sound insulation, impact sound insulation, façade insulation, sound radiation to the outside, sound due to service equipment and reverberant sound in enclosed spaces. So these became the six parts of the standard, drafted by working group 2 of CEN Technical Committee 126 'Building Acoustics'. For various building elements the product quantities and their measurement methods were well established so these could be used as input to the prediction (estimation) of the building performance. But drafting these prediction models made clear what type of input data was still missing and what

type of product quantities and measurement methods should be added. This generated activities in other working groups to define methods and in various countries to collect the product performances appropriate for the local building situations. An overview will be presented of these developments so far and the items still to be covered or improved.

[13] Lentzen, S., Koopman, A and Salomons, E. *Assessment of impact noise at 31.5Hz*, 27. June – 1. July 2011, Aalborg.

Summary

Due to the increasing popularity of lightweight building methods, vibrations and low frequency noise have become a greater challenge. This work deals with the assessment of impact noise at the 31.5 Hz octave band. Three possible impact sound sources to determine the sound insulation have been tested and compared in laboratory measurements. It is concluded that the excitation using the rubber ball, as described in Annex F of ISO/DIS 140 part 11, is comparable to that from using the heel-drop method. The latter is described in the Dutch SBR guidelines for walking induced floor vibrations. It is further concluded that the standard hammerbox excitation method, generally used for the assessment of impact sound insulation above 50Hz, is not suitable for the lower frequency range. Due to the possible pronounced modal character of the sound field in the receiving room, it is recommended to introduce the L10 sound level: the sound level that is only exceeded in 10% of the room volume. As it has been proven with extensive tests on human subjects, the A-weighted sound level can be used for the assessment of most sound sources. However, in particular cases penalty factors have to be taken into account.

2 - RESEARCH ACTIVITIES AT LULEA UNIVERSITY OF TECHNOLOGY, DIV OF ENGINEERING ACOUSTICS

Anders Ågren, Fredrik Ljunggren

Relevant for WG1, WG2, WG3 and WG4 - Research during the COST FP0702 action

2.1 - Previous research

Development of a prediction model for impact sound in timber buildings. A three-year PhD student project with national funding. A PhD student has developed the impact sound prediction model of Jonas Brunskog et.al. Moments as well as a de-coupling of floor and ceiling have been added to the model. The project ended during 2011 with a licentiate thesis and two Journal papers, where one is published and one is to be published soon.

Sound insulation variations among nominally identical light weight timber houses. During the COST FP0702 period a nationally funded project has been conducted where variations in impact sound level and airborne sound insulation has been carefully measured in a large number of nominally identical apartments. The project ended 2011-01 and has resulted in two Journal papers and three conference proceedings.

2.2 - Current research

Development of an extended measurement and evaluation scheme for light weight floors. Within AkuLite an extended measurement series is developed and applied on a number of light weight and a couple of concrete structures. The purpose with the measurements, apart from the standardized measurement procedure of impact sound level and airborne sound insulation, is to give more thorough information about the floors like: information about the low frequency behavior, the damping properties, static stiffness, resonance frequencies as well as the vibration propagation in the floor and the flanking transmission over the boundaries.

Low frequency sound and vibrations in light weight timber buildings. Part of AkuLite, a large Swedish national program that is running for three years and ending in the beginning of 2013. Experimental data will be compared to modeled data. Some experimental research at LTU, but the FE modeling research is at Lund TH.

Correlation between extended sound and vibration measurements data and subjective evaluations by the tenants. Within the AkuLite project correlations are being done between objective data and subjective data from written surveys among tenants. The data is measured in matching buildings in order to be comparable. The sound insulation measurements are done according to the extended measurement procedures mentioned above.

Development of improved sound insulation in industrially prefabricated light weight timber houses. A regionally funded project driven together with three house and building part manufacturers. The objective has been to develop the constructions in a cost effective way so that they can stand the Swedish class B level and also perform well at low frequencies. The project has resulted in buildings that fulfill the class B levels. The work is ongoing towards reducing the low frequency sound and reaching the class A level. The project has delivered one Journal paper an two conference proceedings.

2.3 - References with content related to COST FP0702

2.3.1 - Journal papers:

[1] Ljunggren, F. Ågren A. Potential solutions to improved sound performance of volume-based lightweight multi-storey timber buildings. Applied Acoustics, 72, (2011), 231-240.

[2] Ökvist R., Ljunggren F., Ågren A. Variations in sound insulation in nominally identical prefabricated light weight timber constructions. Journal of Building Acoustics, Volume 17 (2010) No 2, 91-103.

[3] Mosharrof, Md.S., Brunskog J., Ljunggren F., Ågren A.,. An improved prediction model for the impact sound level of lightweight floors: introducing decoupled floor-ceiling and beam-plate moment. (2011) Vol 97, No 2., 2011, pp. 254-265 Acta Acoustica with Acoustics.

[4] Öqvist,R., Ljunggren,F., Ågren,A. On the uncertainty of building acoustic measurements - Case study of a cross laminated timber construction. Applied Acoustics, Accepted and resubmitted (Jan 2012).

2.3.2 - Book publication

F. Ljunggren, A. Ågren. Dynamic and Subjective Analysis of a Lightweight/Semi-heavyweight Floor in Laboratory. Paper selected to be included in the book: *Collected papers in building Acoustics: Sound Transmission.* Edited by Barry Gibbs, John Goodchild, Carl Hopkins, David Oldman. Multi science publications, 2009.

2.3.3 - Theses

[1] C. Simmons. Managing uncertainty in building acoustics – Comparisons of predictions using the EN 12354 standards to measurements. PhD thesis LTU 2009.

[2] M.S. Mosharrof. Study and modelling of lightweight floor structure regarding is acoustic properties. Licentiate thesis LTU 2010.

[3] R. Öqvist.Variations in sound insulation in lightweight timber constructions. Licentiate thesis. Licentiate thesis LTU 2010.

2.3.4 - Conference proceedings

[1] Ljunggren, F. Ågren, A., How to improve impact sound insulation in a lightweight module based building system.; ICA, 2007, Madrid, Spain

[2] Ljunggren, F. Improved sound insulation on module based timber framed buildings. BNAM – Joint Baltic-Nordic Acoustics Meeting, 2008, Reykjavik, Iceland.

[3] Ljunggren, F. Changed sound properties due to minor construction changes in a lightweight building. Acoustics´08, 2008, Paris, France.

[4] M.S.Mosharrof, A.Ågren, F.Ljunggren. Prediction model for the impact sound on light weight floors. Inter Noise 2009, Ottawa.

[5] Ljunggren, F. Using elastic layers to improve sound insulation in volume based multi-storey lightweight buildings. InterNoise, 2009, Ottawa, Canada.

[6] Ökvist R., Ågren A., F.Ljunggren. Variations in sound insulation in multi-storey lightweight timber constructions Inter Noise 2009, Ottawa. Invited.

[7] Ågren A. *Acoustic highlights in Nordic light weight building tradition*- focus on ongoing development in Sweden. Keynote speaker BNAM Bergen, May 2010.

[8] Ökvist R., Ljunggren F., Ågren A. Growth of vibro-acoustic properties of volume based timber buildings during the construction phase. ICA 2010, Sydney.

[9] Ljunggren, F. Sound insulation in a six-storey volume based timber building equipped with elastic layers. ICSV 17 – International Congress on Sound & Vibration, 2010, Cairo, Egypt.

[10] Ågren A., Ökvist R., Ljunggren F., Variations in Sound Insulation in Cross Laminated Timber Housing Construction. Forum Acusticum, Aalborg, June 2011. Invited

[11] Ljunggren, F. Long-term effects of elastic glue in lightweight timber constructions. Forum Acusticum, 2011, Aalborg,

3 - RESEARCH ACTIVITIES AT LIVERPOOL UNIVERSITY

Carl Hopkins

Relevant for WG1 and WG2

3.1 - Current research

Supervision of four PhD students who are studying topics with potential application to timber-frame structures. Matthew Robinson is studying the practicalities of using a transient form of SEA to predict maximum sound pressure levels in spaces due to transient structure-borne sound sources (started 2008, finishes 2012). Jianfei Yin is studying how ribbed plates can be incorporated into SEA models (started 2009, finishes 2013). Claire Churchill is studying direct and flanking transmission across hybrid lightweight-heavyweight floor systems (started 2010). Wang Xing is studying the prediction of vibration transmission across complex networks of beams with point-connected plates (started 2012, finishes 2015).

EPSRC funding (2010-2013): Reception Plate Method for Structure-Borne Sound Sources. This project will investigate the characterisation of structure-borne sound sources using the reception plate and its application to lightweight structures.

Previous research

Primarily on prediction and measurement relating to sound transmission in buildings.

3.2 - Available papers / presentations

[1] Hopkins C (2002) Laboratory measurement of the sound reduction index improvement by acoustical linings due only to resonant transmission. Forum Acusticum 2002. Forum Acusticum, Seville.

[2] Carl Hopkins, “Sound Insulation”, Elsevier / Butterworth-Heinemann (622 pages). ISBN 978-0-7506-6526-1 (2007)

[3] J. Yin and C. Hopkins. Determination of coupling loss factors between L-junctions of coupled homogenous and periodic plates using finite element models. ICSV, Cairo, Egypt.

[4] Hopkins C (2009) Sound insulation in timber-framed buildings - Improving the reliability and relevance of field measurements in the low-frequency range. Acoustics for Timber-based Lightweight Buildings and Elements. COST Action FP0702, Vaxjo, Sweden.

[5] Hopkins C (2009) Influence of the physical test set-up and in-plane waves on the measurement of flexural wave coupling parameters between heavyweight building elements. Proceedings of Euronoise. Edinburgh.

[6] Hopkins C (2009) Spatial sampling of sound pressure in rooms using manual scanning paths. Proceedings of Euronoise. Edinburgh.

[7] Hopkins C (2009) Sound insulation in timber-framed buildings - Improving the reliability and relevance of field measurements in the low-frequency range. Acoustics for Timber-based Lightweight Buildings and Elements. COST Action FP0702, Vaxjo, Sweden.

[8] Yin J and Hopkins C (2010) Determination of coupling loss factors between L-junctions of coupled homogenous and periodic plates using finite element methods. Proceedings of ICSV. International Congress on Sound and Vibration, Cairo.

[9] Hopkins C (2010) The effectiveness of manual scanning measurements to determine the spatial average sound pressure level in rooms. Internoise 2010. I-INCE, Lisbon.

[10] Robinson M and Hopkins C (2010) Prediction of maximum sound pressure and vibration levels in heavyweight building structures using Transient Statistical Energy Analysis. Internoise 2010. I-INCE, Lisbon.

[11] Hopkins C (2011) Revision of ISO Standards on field sound insulation testing. EU COST Networks FP0702 and TU0901. EMPA, Zurich.

[12] Yin J and Hopkins C (2011) Using the framework of Statistical Energy Analysis to incorporate tunnelling mechanisms for bending wave transmission across a ribbed periodic plate. Proceedings of Internoise 2011. I-INCE, Osaka.

[13] Hopkins C and Robinson M (2011) Using Transient Statistical Energy Analysis to assess errors in the total loss factor determined from measured structural reverberation times in building acoustics. Proceedings of Internoise 2011. I-INCE, Osaka.

[14] Robinson M, Hopkins C (2011) Predicting the effect of coupled spaces and structures on structural decay curves of building elements using Transient Statistical Energy Analysis. Proceedings of ICSV 2011. International Congress on Sound and Vibration, Brazil.

[15] Robinson M, Hopkins C (2011) Signal processing errors associated with the measurement of maximum sound pressure levels. Proceedings of ICSV 2011. International Congress on Sound and Vibration, Brazil.

[16] Robinson M, Hopkins C (2011) Transient Statistical Energy Analysis: A two-subsystem model to assess the validity of using steady-state coupling loss factors for plate radiation. Proceedings of ICSV 2011. International Congress on Sound and Vibration, Brazil.

[17] Churchill C, Hopkins C, Krajci L (2011) Modelling airborne sound transmission across a hybrid heavyweight-lightweight floor using Statistical Energy Analysis. Proceedings of Forum Acusticum 2011. Forum Acusticum, Denmark.

[18] Wilson D, Hopkins C (2011) Prediction of low frequency structure-borne sound transmission between non-adjacent rooms in buildings using SEA and FEA. Proceedings of Forum Acusticum 2011. Forum Acusticum, Denmark.

[19] Hopkins C (2011) On the efficacy of spatial sampling using manual scanning paths to determine the spatial average sound pressure level in rooms. Journal of the Acoustical Society of America vol 129 issue 5 pp 3027-3034.

4 - RESEARCH ACTIVITIES AT CSTB

Michel Villot, Catherine Guigou-Carter

Relevant for WG1 and WG2

4.1 - Current research

CSTB study planned for 3 years (2008-2010), and financially supported by DHUP (French Ministry of Housing) on simplified prediction model for estimating lightweight building performances at design stage. Because of the great variety of wall type, floor type and junction type, the main idea is to group all the elements and junction between elements into a few categories represented by characteristic (mean) parameters such as R index, radiation efficiency or vibration level difference … obtained with the use of combined measured / calculated data.

CSTB, financially supported by DHUP (French Ministry of Housing) in 2011 focused on noise from service equipment installed in timber based lightweight buildings.

Acoubois project: partners: CSTB, FCBA (French center for wood construction) and QUALITEL; financially supported by ADEME, DHUP, CODIFAB (wood manufacturer organization) and the various industrial partners. Phase 1 of the project in 2010: gathering and categorizing the different building elements and junctions between elements used in France in timber based lightweight buildings; identification of missing data. From 2011 to 2013, laboratory components acoustic performance measurements as well as junctions characterization measurements and in-situ building acoustic performance measurements, are being and planned to be performed. These measurements are to be used in validating, updating the prediction method for lightweight construction, as well as the development of a simplified method for QUALITEL. A survey based on questionnaire will also be carried out to evaluate the perception and acceptability of such lightweight buildings.

4.2 - Previous research

Study on prediction and measurement methods based on European standards (140 and 12354 series) and adapted to wood frame lightweight constructions, financially supported by ADEME (French Agency for Environment and Energy) and DHUP (French Ministry of Housing).

CSTB partner of the European project ACOUSVIBRA on the acoustics and low frequency vibration of steel frame lightweight constructions.:

- CSTB has developed a new calculation model for the acoustic performance of single frame lightweight walls, based on a combination of wave approach and SEA
- CSTB has adapted standard EN 12354 - 1 and 2 to the prediction of flanking transmission in steel frame lightweight constructions

4.3 - Available papers / presentations

[1] "Measurement methods adapted to wood frame lightweight constructions", M. Villot and C. Guigou, Building Acoustics, volume 13, number 3, 2006

Abstract

When building elements of wood-frame lightweight constructions are considered, laboratory acoustic measurement methods have to be rethought. Indeed, because lightweight elements are often highly damped, the vibrational fields are no longer reverberant and existing standards often lose relevance, particularly in the case of mechanical excitation (such as in impact noise measurements or in vibration reduction index measurements of junctions). In this paper, standardized methods are identified or new methods are proposed for characterizing lightweight elements in order to obtain input data for prediction models such as that adapted from the standards EN 12354-1 and -2 and described in a companion paper. Moreover, it is shown that a new parameter (the radiation efficiency) is required when predicting the performance of lightweight buildings. Measurement results are shown for both wall and floor elements and the results are discussed, particularly in comparison with heavy building elements

[2] "Prediction methods adapted to wood frame lightweight constructions", C. Guigou and M. Villot, Building Acoustics, volume 13, number 3, 2006

Abstract

When wood frame lightweight constructions are considered, both the standardized methods, EN 12354-1 and -2, for predicting building performances from the performances of building elements and the related standardized laboratory measurement methods for characterizing building elements and their junctions have to be reconsidered. In this paper, a prediction method based on Statistical Energy Analysis and adapted to lightweight constructions, is presented. It was applied to a two-storey four-room building where an analysis of the different transmission paths was required in order to understand and improve the acoustic performances of the building. Comparisons between results, expressed in terms of airborne and impact sound insulation between rooms, either directly measured or calculated using the prediction method, are given in the three cases of vertical, horizontal and diagonal transmission. A satisfactory agreement between calculated and measured results is obtained.

[3] Research Program of the Research Fund for Coal and Steel, Technical Group TGS 8, "High Quality Acoustic and Vibration Performance of Lightweight Steel Constructions", Final report of project RFS-CR-03025 (published in 2007)

[4] "Predicting sound insulation in wood frame buildings", M. Villot and C. Guigou, Internoise09, Ottawa Canada, proceedings

Abstract

The vibration response of wood frame lightweight constructions is different from the response of heavy structures, particularly because of the presence of non-uniform vibration fields, relatively high attenuation (high internal loss factors) and non-resonant fields; these particularities have to be taken into account in predicting sound insulation and require more input data than for heavy structures. There is also another difficulty: the variety of building elements (using different types of boards, studs, joist…) and of junctions between elements is so great that it is impossible to measure the performance of all the possible elements and junctions. This paper deals with this difficulty by grouping building elements and junctions between elements into a smaller number of categories represented by characteristic parameters such as the known sound reduction index R or the vibration level difference Dv,ij (or related junction invariant), but also the less known radiation efficiency σ, all obtained with the use of combined measured and calculated data. A few practical examples are presented.

[5] "Comparison between measured and predicted sound insulation in wood frame lightweight buildings", C. Guigou, M. Villot and R. Wetta, Internoise10, Lisbon Portugal, proceedings

Abstract

When wood frame lightweight constructions are considered, the standardized methods, EN 12354-1 and -2, for predicting building performances from the performances of building elements have to be modified. A prediction method based on SEA and adapted to lightweight constructions requiring more input data than for heavy structures has been introduced by CSTB. Recently, some simplifications have been introduced by grouping building elements and junctions between elements, into a small number of categories represented by characteristic parameters. Laboratory and in-situ measurements have been carried out on a wood frame lightweight building and some of its elements. Comparisons between results expressed in terms of airborne and impact sound insulation between rooms, either directly measured or calculated using the prediction method are presented; these results, including or not the simplified approach, are given in the cases of vertical and horizontal transmissions.

[6] "Predictions and measurements for lightweight constructions and low frequencies ", C. Guigou and M. Villot, Euronoise10, Prague Czech Republic, proceedings

Abstract

In this work, a prediction method based on the EN 12354-1 and -2 approach and adapted to lightweight construction is presented. The measurement procedures to evaluate the different model input parameters such as the radiation efficiency of elements and the vibration level difference associated to junction between elements are introduced and discussed. The use of the finite element method to estimate the vibration level difference associated to junctions is also investigated. The prediction method to evaluate the building acoustic performance is tested with some simplifications to limit the number of measurements of the input parameters. Comparisons between measurement and prediction results in terms of airborne and impact sound insulation down to low frequencies (below 100 Hz) are given to access the relevance of the prediction model for vertical and horizontal transmission.

[7] "Prediction of structure borne noise in heavyweight and lightweight constructions", M. Villot and S. Bailhache, 19th ICSV, Vilnius Lithuania, proceedings

Abstract

This work aims at predicting and comparing the structure-borne noise due to building ser-vice equipment, installed in heavyweight or lightweight buildings, taking waste water pipes as an example. The structural power injected into the supporting structure is estimated using a source and receiver mobility approach; this part of the work is presented in a companion paper. For heavy constructions, the structure borne noise prediction is made according to standard EN 12354-5. For lightweight constructions, a modified approach is proposed according to the recent work performed in the frame of COST Network FP0702 and using two new quantities: the sound reduction index referring to resonant transmission only and a junction invariant expressed as normalized direction average velocity level difference. Comparisons between heavy and lightweight constructions are made in terms of injected structural power (companion paper), supporting structure velocity field, velocity level difference at junctions and structure borne sound pressure level radiated.

[8] "Prediction of structure borne noise in heavyweight and lightweight constructions", S. Bailhache and M. Villot, 19th ICSV, Vilnius Lithuania, proceedings

Abstract

The purpose of this work is to compare the structure-borne sound power injected into build-ing elements due to building service equipment, in heavyweight or lightweight construction. The case of waste water pipes rigidly fixed to a separating wall is considered, this wall being made either of concrete or of gypsum boards on wood frame. The structure-borne sound power injected into the supporting structure is calculated using a source and receiver mobility approach. Characterization measurements are carried out to determine the duct free velocity under various water flows as well as the source and receiver mobilities determined using an electrodynamic shaker excitation. Different expressions for the injected power are used, de-pending on the source receiver mobility conditions. Calculation results, given in 1/3 octave bands, are discussed. The estimated values of structural power are used in a companion paper as input data for a prediction model leading to radiated noise in adjacent rooms.

4.4 - Network on lightweight wood constructions

An horizontal network of CSTB agents working on lightweight wood constructions in different domains (structural stability, fire, thermal insulation, acoustics, air and water proofing…) has been created; common meetings should contribute to a better mutual information within CSTB.

There is an agreement between CSTB and FCBA (both members of Action FP0702) in order to improve the coordination / collaboration between the two institutes ; meetings will be regularly organized in acoustics.

5 - RESEARCH ACTIVITIES IN GERMANY, ROSENHEIM

Joachim Hessinger

Relevant for WG1 and WG4

5.1 - Current research

Vibration behaviour of timber-floors in frequency range below 100 Hz, TU Munich and Hochschule Rosenheim, started in 2010

5.2 - Previous research

- revision of collection of construction examples of timber building elements for DIN 4109, PTB 2005
- Flanking transmission of impact sound in timber floors, ift Centre for Acoustics, 2005
- Calculation model for timber wall constructions, ift Centre for Acoustics, 2006
- Construction principles for the application of lightweight construction elements in the interior construction, Hochschule Rosenheim, 2008
- Timber joist floors in renovation of buildings – part 1, ift Centre of Acoustics, 2008
- Vibration and attenuation behaviour of timber-floors and timber-concrete-composite floors, TU Munich, 2009
- FEM based prediction model for the impact sound level of floors, TU Munich, 2009
- Application of Helmholtz resonator for improvement of sound insulation between rooms in timber buildings, Hochschule Rosenheim, 2010
- Timber joist floors in renovation of buildings – part 2: Flanking transmission, Hochschule Rosenheim, ift Centre of Acoustics, 2012

5.3 - Planned research

- Integrated design of the vibro-acoustical performance of multi-storey buildings based on solid wood
- Elements, TU München, Hochschule Rosenheim, ift Centre of Acoustics, application in 2012

5.4 - Available papers / presentations

[1] Rabold, A., Düster, A., Hessinger, J., Rank, E., "Optimization of lightweight floors in the low frequency range with a FEM based prediction model", Tagungsband DAGA 2009

Abstract

The impact noise transmission at low frequencies is a well known problem of lightweight floors, which is treated in many publications. A satisfying solution, considering the different construction principles of lightweight floors, could not be found so far. To overcome this problem a FEM based prediction model for the optimization of the floor construction and the improvement of the impact sound insulation has been developed and applied in a current research project at the TU München. The overall approach of the prediction model consists of the three-dimensional modelling of the structure and the excitation source (standard tapping machine), the subsequent modal- and spectral analysis and the computation of radiated sound from the ceiling. The validation of the prediction model has been carried out by comparing the evaluated impact sound pressure levels with results from measurements on 25 different floor constructions. In the next step the prediction model was used for the improvement of established lightweight timber floors. Finally these constructions were tested in a laboratory test stand according to ISO 140-6 at ift Rosenheim centre for acoustics and the ibp Stuttgart. This contribution shows the results of the computations and the construction rules developed for optimized lightweight floors.

[2] Rabold, A., Hamm, P., "Schall- und schwingungsoptimierte Holzdecken", bauen mit holz, 4, 2009, 38-43

[3] Rabold, A., Hessinger, J., Bacher, S., Schallschutz, Holzbalkendecken in der Altbausanierung, Mikado plus, 3, 2008

[4] Rabold, A., Wissel, C., Schanda, U., Hessinger, J., Prognose der Schalldämmung von leichten Trennwänden, Tagungsband DAGA 2010

[5] Schramm, M., Dolezal, F., Rabold, A., Schanda U., Stoßstellen im Holzbau – Planung, Prognose und Ausführung, Tagungsband DAGA 2010

[6] Otto, J., Schanda, U., Schramm, M., Wolf, M., Helmholtzresonatoren zur Absorption tieffrequenten Trittschalls, Tagungsband DAGA 2010

[7] Hessinger, J., Rabold A., Saß, B., Schallschutz im Holzbau, in: Fouad, N.A., Bauphysik Kalender 2009, Ernst und Sohn Verlag, 2009

6 - RESEARCH ACTIVITIES IN GERMANY, PTB

Heinrich Bietz

Relevant for WG1 and WG4

6.1 - Previous research

6.1.1 - - Installation Noise test facility [1]

Discussions with the German association of manufacturers of prefabricated houses (BDF) showed a growing concern towards the behaviour of installation noise generated by sanitary equipment in lightweight buildings. At PTB, a test facility which represents a two-storey prefab house, was created. Its main objectives are a) to enable companies organized in BDF to test the acoustic behaviour of their sanitary installations and b) give PTB the opportunity to do basic research on this topic with the long-term aim of defining a prediction method for installation noise and also a standardised laboratory test setup. The test facility started operation in 2004. Until today, 11 companies have performed tests in the facility. The results are collected and interpreted by PTB. They show that it is basically possible to meet the German requirements on installation noise in a lightweight building, though there is a wide spread in the results. Furthermore, the wastewater-pipe showed up as a major sound source, thus making it subject of further research.

6.1.2 - Characterisation of a waste water pipe as a sound source [4]

As the waste water pipe presented itself as a major sound source, closer attention was given to it. First the point mobility was measured with different fixtures and also with the pipe filled with different amounts of water. Results showed that the influence of water in the pipe is not very significant with respect to point mobility.

In a second step, a wastewater pipe was characterised as a sound source using the 2-stage-method recently suggested by Gibbs et al..

Furthermore, research was done on the influence of different fixture systems on the transmitted sound power, the final report still has to be finished.

In all, it turned out that the waste water pipe has a source mobility which is in the same range as the input impedances of lightweight walls, thus enabling a good power transfer into these structures.

6.1.3 - General measurements on lightweight structures [2]

Numerous mobility and transfer function measurements were performed on lightweight structures, including those of the Installation Noise Test Facility, selected prefab houses and a plasterboard / metal stud configuration (T-junction). One major outcome of this is that the point mobilities of the investigated structures are comparable with a reasonable spread, as long as they are lightweight.

The aforementioned topics are well compiled in a report for the German federal building agency. Unfortunately, it is available only in German. I will try to get permission to publish it on the action website anyway.

6.1.4 - Verification of the two-stage-method (TSM) [3], [4]

This method, proposed by Gibbs et al., can be a valuable tool to characterise the source quantities of complex structure-borne sound sources. One of its possible drawbacks is that it employs certain simplifications to have it implemented properly. Research was done at PTB to validate this method by characterising sources with known characteristics. Major outcomes are that the method works with reasonable accuracy, but selection of the proper receiving plates may be critical, depending of the source characteristics. Future research will be an attempt to characterise a human walker with help of the TSM.

6.2 - Current research

6.2.1 - - Characterisation of the human walker as a sound source [4]

Based on previous research, first attempts have been done to characterise the human walker as a sound source using the two-stage-method. The initial results are promising, and research is currently focusing on the selection of suitable receiving plates.

6.2.2 - Collection of data related to installation noise and structure-borne sound parameters in lightweight buildings

Parallel to the research in the installation noise test facility, several measurements in finished prefab house are performed, with more to come. The measurements include installation noise as well as structure-borne sound parameters like point mobilities and transfer functions. One of the aims of these measurements is to find out whether transfer functions can be used for a prediction of installation noise. In addition to these measurements there is a cooperation with researchers from Weimar university with the focus on the assessment of transfer functions

6.2.3 - Compact measurement setup for the determination of impact noise reduction

A compact measurement setup for the determination of impact noise reduction (COMET) has been developed in PTB. Until now, it works successfully for concrete floors and locally reacting coverings. PTB has applied for a research project with the aim to extend the applicability of this device to wooden floors and plate-like floor coverings like parquet floors etc..

6.2.4 - Research on walking noise emission and impact noise reduction of laminate floorings [5]

PTB is currently conducting a round robin test on the assessment of walking noise emission and noise transmission reduction of laminate floorings. The major objective is the establishment of a standardized procedure for the measurement of walking noise. Actually, the test samples are sent to the participants. 21 laboratories from Germany, France, Poland, Sweden, Denmark, Spain, The Netherlands, Belgium and Switzerland will take part in the round robin.

6.3 - Available papers / presentations

[1] Bietz, H., Wittstock, V., Scholl, W., Prüfstand zur Bestimmung von Installationsgeräuschen im Holz- Fertigbau- Neue Messergebnisse und Entwicklungen - , Proceedings DAGA 2006, Braunschweig March 2006

[2] Kling, C., Wittstock, V., Bietz, H., Studie zur Anwendbarkeit des Prognoseverfahrens nach prEN 12354-5 und damit zusammenhängender Labormessverfahren (CEN TC 126/WG 7) im Leichtbau, Abschlussbericht BBR-Projekt Z6-10.07.03-06.18 / II 2-800106-18

[3] Wittstock, V., Bietz, H., Characterising sources of structure-borne sound by the Two Plate Method; Proceedings NOVEM 2009, Oxford, April 2009

Abstract

The assessment of the ability of a vibratory source to inject sound power into a receiver is a major task in different fields of acoustics. Recently, Gibbs et. al. proposed to characterise structure-borne sound sources by two properties, an activity and a mobility quantity. They are determined by connecting the source under test to two different receiving plates with different point mobilities. From the different sound powers injected into the different receiving plates, source quantities can be calculated. At PTB, this method has been used to determine the source characteristics of an electrodynamic shaker. This source has the advantage that it can be modelled by electromechanic analogies and, thus, source properties can be determined by a second method. Additionally, the power input into the receiving plates can be measured by an impedance head and the electric power input is also known. Furthermore, impulse signals can be used as well as stationary ones and the mechanical structure can be manipulated very easily. The results presented will include comparisons between sound powers and source quantities determined by different methods for stationary and impulse signals for different sources.

[4] Wittstock, V., Characterisation of structure-borne sound sources in buildings by the two-stage reception plate method, Proceedings InterNoise 2010, Lisbon, April 2010

Abstract
Structure-borne sound sources must usually be described by at least two source properties, an activity and a mobility quantity. The two-stage reception plate method was proposed as a practical means to determine these source quantities. The method requires the determination of structure-borne sound powers in two receiving plates, one with a higher and one with a lower mobility than the source mobility. The contribution gives an overview of recent applications of the two-stage method to realistic structure-

borne sound sources in buildings such as waste water systems with different clamps, walking persons and free water jets.

[5] Scholl, W., Messung von Gehgeräuschen, Proceedings DAGA 2010, Berlin, March 2010

7 - RESEARCH ACTIVITIES IN AUSTRIA, HFA AND TGM

Franz Dolezal, Herbert Müllnerrelevant for WG1

7.1 - Current research

7.2 - Previous research

7.2.1 - Flanking transmission of impact noise at solid wood structures

3-years research project on predictions and measurements of direct and flanking transmission with solid wood floors and wooden floors with flexibel interlayers (Holzforschung Austria (HFA) in cooperation with TU-Vienna) 2006-2008:

Since solid wood constructions are more frequently applied for multy-storey residential buildings, demand for reliable prediction of sound insulation is increasing. Prediction is generally carried out following EN 12354 which, however, does not contain any input data for solid wood constructions.

For creating an extensive collection of data for direct and flanking transmission in solid wood structures, planning and construction of test facilities was required. Three different types of solid wooden floors and four different flexible interlayers were investigated. Additional measurements were carried out with additional load to simulate the situation of multy storey buildings and with different types of fasteners.

Therefore, sound- and vibration measurements are realized on solid wood test facilities where flanking transmission and input data for standardized predictions are acquired. The normalized impact sound pressure level is calculated for different flexible interlayers and compared to the results of the measurements. Single number quantities show satisfactory accordance between measurement and prediction with deviations between 0 and 2 dB. Considering frequency dependent values major deviations, which can be detected in a certain frequency range, require more accurate modelling.

Hence, the impact of flexible interlayers is highly affected by installation of required metal fasteners, in a further step, application of gathered results to the building situation by the use of fasteners had to be investigated. By means of sound and vibration measurements the acoustic impact of fasteners was quantified and assigned to the particular type of connection. Optimized fasteners were verified in respect of their acoustical and load bearing performance.

Considering former expertise of measurements carried out in test facilities, a prediction model was developed. In this model the junction is defined only by properties of flexible interlayers, load and fasteners. Comparing measurement and calculation leads to satisfying results.

A catalogue of verified constructions was published ("Deckenkonstruktionen für den mehrgeschossigen Holzbau – Schall- und Brandschutz, Detailkatalog" – Holzforschung Austria) to enable quick estimation of acoustic parameters of selected constructions, including flanking transmission.

7.2.2 - Feasibility Study on low frequencies in light weight constructions.

Short study with international partners guided by TGM Vienna 2009-2011.

The reason for this study is that acoustical development is based on knowledge for heavy weight mode of construction. Because of this fact, the aim to consider the extended frequency range down to 50 Hz to become an established part of standards and legislations. The sound insulation properties between dwellings and between apartments are currently a vivid discussed topic in many European countries. The study will deliver basics and proposals based on the conclusions of the state-of-the-art and the supposed future situation regarding the effect on the "building with wood sector" and actions which have to be taken into consideration to face the upcoming challenges well prepared and to keep the

concerned industry sector competitive. To avoid a loss of sympathy for light weight mode of construction and to keep the building with wood industry competitive action is needed.

A feasibility study should clarify the current situation, the intermediate as well as long term prospects

to get a basic knowledge what actions have to be done, to keep the building with wood industry competitive.

Experts from different European countries were invited to work on this study.

1. Round robin test (organized by TGM Vienna 2008-2010) into impact sound of light weight floors – solid wood and joist floor - with special attention to low frequencies in small receiving rooms.
2. Analysis of structure-borne sound transmission in solid wooden constructions – master thesis carried out at TU Vienna

7.3 - Planned research

7.4 - Available papers / presentations

[1] Dolezal, Franz; Bednar, Thomas: Schall-Längsleitung bei Massivholzkonstruktionen. Proceedings DAGA 2008, Dresden.

[2] Dolezal, Franz; Bednar, Thomas: Einfluss von Befestigungsmitteln auf die Schall-Längsleitung von Massivholzkonstruktionen. Proceedings DAGA 2010, Berlin.

[3] Dolezal, Franz; Teibinger, Martin; Bednar, Thomas: Flanking Transmission of Impact Noise at Solid Wood Structures. Proceedings World Conference on Timber Engineering WCTE 2010, Bd. 3. Riva del Garda, Trento, Italy.

[4] Dolezal, Franz; Bednar, Thomas; Teibinger, Martin: Flankenübertragung bei Massivholzkonstruktionen, Teil 1. Verbesserung der Flankendämmung durch Einbau elastischer Zwischenschichten und Verifizierung der Anwendbarkeit von EN 12354. *Bauphysik* 30 (3), 2008.

[5] Dolezal, Franz; Bednar, Thomas; Teibinger, Martin (2008): Flankenübertragung bei Massivholzkonstruktionen, Teil 2. Einfluss von Befestigungsmitteln auf die Verbesserung durch den Einbau elastischer Zwischenschichten. *Bauphysik* 30 (5), 2008.

[6] Müllner, Herbert; et.al.: Sound Insulation in the Low Frequency Range Prospects and Recommendations to keep the Building with Wood Industry competitive. TGM 2011, Vienna.

[7] Müllner, Herbert; Stani, Mathias: Ringversuch Teil 2 - Messung des Luft- und Trittschallschutzes von Decken in Holzbauweise mit besonderem Fokus auf dem erweiterten Frequenzbereich unter 100 Hz. Bericht zum Ringversuch Teil 2, Messungen an einer Holzbalkendecke. TGM 2010, Vienna.

[8] Müllner, Herbert; Stani, Mathias: Ringversuch Teil 1 - Messung des Luft- und Trittschallschutzes von Decken in Holzbauweise mit besonderem Fokus auf dem erweiterten Frequenzbereich unter 100 Hz. Bericht zum Ringversuch Teil 1, Messungen an der Brettstapeldecke. TGM 2010, Vienna.

[9] Hanic, Radoslav: Analysis of structure-borne sound transmission in solid wooden constructions. TU Vienna. Zentrum für Bauphysik und Akustik 2009, Vienna.

8 - RESEARCH ACTIVITIES AT TECNALIA

Marta Fuente González

Relevant for WG1 and partly WG2

8.1 - Current research

EGOSOINU: Industrialised constructive system for timber based multistory dwellings. EUREKA project "ECO-HOUSE". (2011-2014). Acoustic design of a constructive system based on cross laminated timber (CLT) products with enhanced acoustic performances with a Spanish wood panel manufacturer EGOIN. The project will focus on in situ acoustic performances of CLT systems taking into account laboratory measurements, vibration behaviour of joints and technical problems related to lightweight constructions. The objective is fulfilling Spanish and French acoustics requirements, and without forgetting other characteristics as fire protection, seismic behaviour, etc.

8.2 - Previous research

- CETICA (2007-2011): a big project of **lightweight construction based on steel** which is leaded by **Arcelor Mittal** and co-financed by Ministry of Science and Innovation. The objective of the project is to design and to develop new and advanced materials and constructive systems, based on steel, for a new model of building efficient echo energetically, inside a sustainable development with a clear orientation towards the final user. This project will allow to **industrialize the construction sector in a steel base**. In this project the acoustic performance was a very important task. (www.arcelormittal.com/cetica , in Spanish).
- BALI (2009-2011): Comprehensive design of acoustically efficient systems and buildings in a health-giving environment. Improvement in the acoustic characteristics of architectural products and greater efficiency from the acoustic comfort point of view and without neglecting other aspects to do with sustainability, in particular to do with energy saving. It is leaded by **FCC** and financed by Ministry of Science and Innovation. There are two projects inside about: lightweight facades and polymeric composites façade panels.
- ERAHONTEK (2008-2009): Development of multimaterial facade panels based on plastic and stony waste from building and demolition. Developed prototypes have been characterized mechanically, thermally and acoustically. It has been financed by Diputación Foral de Bizkaia.
- In Spain, nowadays the construction of buildings is heavy weight. Even in single-family houses light weight construction is practically nonexistent. Although mixed construction (light and heavy weight) is more usual than in the past, but only with

some light weight elements for facades, walls or roofs. The floors are still being heavy weight.

- The acoustical quality of dwellings in Spain is going to be guaranteed with the compliance of the new Spanish Building Regulation (CTE-DB HR). Searching a higher level of comfort in dwellings the CTE is increasing its requirements and is considering the building as a product itself. This new Regulation is compulsory since April 2009.
- Manufacturers of the constructive sector in Spain are launching many innovative research strategies for the development of better products, addressing key factors for the energy efficiency of buildings and the acoustic improvement.
- So our previous researches in building acoustics have been focused on improve the more usual and traditional Spanish construction elements, for example: on the optimization of ceramic brick double walls with peripheral resilient layers, to be used to separate dwellings (2003-2009).

8.3 - Available papers / presentations

[1] Perez, M.; Fuente, M.; Guigou-Carter, C. Predicting and measuring the acoustic performances of lightweight based buildings. Congrès Français d'Acoustique 2012, Nantes.

[2] Fuente, M.; Arines, S.; Elguezabal P.; de Rozas, M.J.; Perez, M. Industrialized lightweight floors for multi-storey dwellings in Spain. FORUM ACUSTICUM. Aalborg (Dinamarca), 2011.

[3] Arines, S.; Fuente, M. Modelling the acoustic behaviour of ceramic brick double walls with peripheral resilient layers. Euronoise 2009, Edinburgh, 2009.

[4] Arines, S.; Cortés, A.; Fuente, M.; Guigou-Carter, C., Claude, M.; Villot, M. Optimization of ceramic brick double walls with peripheral resilient layers. ICA, Madrid, 2007.

8.4 - Additional information

- Now we are Tecnalia, as a result of the merger of 8 technological centres. We have combined our capabilities to work in different areas of construction: acoustic, thermal, energy saving, fire protection, wood technology, nanotechnology… www.tecnalia.com
- We have designed and built a new building for tests, trials and monitoring. It is intended to enhance knowledge not only in acoustics, but also in thermal behaviour and energy efficiency. http://edificacionindustrializada.com/multimedia/

9 - RESEARCH ACTIVITIES AT BBRI

Bart Ingelaere

Relevant for WG1 and partly WG2

9.1 - Current research

The current researches are financed by the DGTRE and IWT for the projects OSSABOIS and AH+ respectively. The research runs for 2 years.

- Development of building guidelines for wooden construction
  The challenge is to reduce the flanking transmissions in an as economic as possible way. We study here the applicability of resilient joints at junctions to improve the reduction of the structural transmission. The application of resilient joints at junctions was studied in the case of lightweight masonry walls and has shown a very good improvement of the sound insulation between rooms. Different joints (rubber, felt,..) are (and will) tested in laboratory and insitu.

- Development of procedures to measure the attenuation of the vibrational power flow through a junction joining lightweight walls
  As we have found earlier, lightweight walls with a large damping factor show an important attenuation of the vibration level with distance. Moreover, these complex wall systems (e.g. gypsum boards on a wooden or metallic frame) don't behave as homogeneous monolithic walls, making it difficult to interpret the attenuation of the vibration level. Hence, the use of the « VLD » method for these kinds of walls is not appropriate. At the BBRI acoustic laboratory, we have developed a test setup destined to measure in particular the influence of a junction on the attenuation of the vibrational power flow by using sound intensity measurements (method 1). Subsequently, we have developed another method (method 2), more simple to implement, which is inspired by the work of E. Gerretsen. This second method is in fact an adaptation of the « VLD » method. A short description of these two methods can be found on the cost-website.
  These new methods will be validated by experimental measurements in laboratory and by FEM models (ACTRAN 2007.3).

9.2 - Previous research

MEZ/MAE 2006-2008 : a prenormative research financed by the ministry of economics affairs (Belgium). In this research we have developed the new measurement methods of Kij for lightweight construction. Report in French.

9.3 - Available papers / presentations

[1] C. Crispin, B. Ingelaere and G. Vermeir. Innovative building systems to improve the acoustical quality in lightweight masonry constructions: Application of resilient joints at junctions - PART 1: analysis of the experimental results, Acoustics08, Paris

[2] C. Crispin, B. Ingelaere and D. Wuyts. Innovative building systems to improve the acoustical quality in lightweight masonry constructions: Application of resilient joints at junctions - PART 2: Study cases modelled according to the standard 12354-1 (2000). Acoustics08, Paris

[3] MEZ/MAE 2006-2008 – report only in French

10 - RESEARCH ACTIVITIES AT SINTEF BUILDING & INFRASTRUCTURE

Anders Homb

Relevant for WG1 and WG2

10.1 - Current research:

A research project funded by NFR (The Research Council of Norway) and an industry partner named "Modern timber floor constructions" is running. The project period is from 2011 to 2012. The scope is on static and dynamic properties of beam constructions with open web joist timber beams. The project also contains activities related to fire and sound insulation challenges when installing technical installations in the beam construction. The project is organized with different Work Packages and contains measurements, simulations and support to secure quality of buildings in progress. The overall objective of the project is to develop methods and gain knowledge and competence to design constructions with double span with solutions and integrated installations.

10.2 - Previous research:

A research project funded by NFR (The Research Council of Norway) and the industry called "Comfort properties of timber floor constructions" is finished. The project period was from 2006 to 2010. The scope was on the vibration response of floor constructions exposed to human activities and common vibration sources in relevant building categories. The project is organized with different Work Packages. One PhD student is working on numerical modeling, but with connection to an experimental program. We have also assigned M.Sc. students to this project at the involved universities, NTNU and UMB. The overall objective of the project was to develop methods and gain knowledge and competence to design timber floor constructions with increased span width compared with existing, common solutions.

Research work have been carried out with NFR and relevant industry concerning sound transmission in buildings with cross-laminated timber floors and walls. The project period was from 2009 to 2011. The scope is especially on the sound transmission at junctions between floor and wall elements. The project is organized with work packages concerning existing knowledge, calculations and measurements. The objective of the project is to develop solutions reducing the flanking transmission at the junctions.

Different research projects with the Norwegian industry on characterizing sound transmission of light weight building systems in general, mainly timber based solutions. Both calculations and measurements have been carried out. The main focus has been on practical application.

10.3 - Planned research

Research project together with different industry partners. We want to develop timber beam constructions with improved impact sound insulation properties at low frequencies. The scope is on acceptable perception of the floors compared with common solutions used so far in Norway.

We are also trying to establish a larger project with funding from NFR related to timber construction and urban buildings. The approval will contain a wide range of items, for instance architecture, building technology and structures (load bearing, vibrations, acoustics, fire and moisture) and implementation.

10.4 - Available papers and reports (ver. may 2012):

- Homb, A (1998). *Ball method for combined low frequency sound insulation and vibration measurements.* Conference proceedings "Acoustic Performance of Medium-Rise Timber Buildings ". Cost Action E5 Workshop, Dublin, Ireland, December 3-4, 1998.
- Homb, A. (2000a). *Floor vibrations using a rubber ball impact method.* Proceedings Nordic Acoustical Meeting, NAM 2000, 5-7. may 2000, Røros, Norway.
- Homb, A. (2000b). *Floor vibrations and low frequency sound pressure levels using a rubber ball impact method*. Proceedings Inter.noise 2000, session 8; Assessment and improvement of floor impact sound in buildings. Nice 27-30. august 2000, France.
- Hveem, S. & al. (2000). *Trehus i flere etasjer. Lydteknisk prosjektering - nordisk samarbeid (Multistorey wood buildings. Designing sound insulation – a nordic cooperation)*. NBI Anvisning 37, 2000 (in Norwegian).
- Stenstad, V. & al. (2003). *Fleretasjes trehus. Hefte 2: Lyd (Multistorey wood buildings. Part 2: Acoustics).* A. Homb og S. Hveem. NBI Håndbok 51, 2003 (in Norwegian).
- Homb, A. (2005a). *Experiences with spectrum adaptation term and extended frequency range from field and laboratory measurements*. Proceedings Forum Acousticum, Budapest Hungary, 29.august – 2. september 2005.
- Homb, A. (2005b). Byggforsk informerer; *Lydisolerende gitterbjelkelag (Sound insulating open web joist timber floor constructions)*. Byggeindustrien nr. 9, 2005 (in Norwegian).
- Homb, A. (2006a). *Excitation methods and impact sound insulation of timber floor constructions*. 2nd Inernational Symposium on advanced Timber and Timber-Composite Elements for Buildings. Acoustic performance and low frequency vibration, 27th April, 2006 Biel – Switzerland, proceedings p. 107-116.

- Homb, A. (2006b). *Low frequency sound and vibrations from impacts on timber floor constructions*. Doctoral theses at NTNU, 2006:132. IME Faculty, Dep. of Electronics and Telecommunications. Trondheim, Norway 2006.
- Homb, A. (2007). *Kriterier for opplevde vibrasjoner i etasjeskillere (Criteria for vibration performance of floor constructions)*. Project report SINTEF Byggforsk, serienr. 8, Oslo 2007 (in Norwegian).
- Homb, A. (2008). *Vibrasjonsegenskaper til dekker av massivtre (Vibration properties of cross laminated timber floors)*. Project report SINTEF Byggforsk, serienr. 24, Oslo 2008 (in Norwegian).
- Homb, A. , Austnes, J.A. *Experiences with sound insulation for cross-laminated timber floors.* Proceedings, Baltic Nordic Acoustical Meeting, Bergen Norway, 10-12. May 2010.
- Kolstad, S.T., Homb, A. *Beregning av nedbøyning til trebjelkelag. Vurdering av parametre og beregningsresultater (Calculation of deflections in timber beam constructions*. *Evaluation of parameters and results)*. Project report SINTEF Byggforsk, serienr. 37, Oslo 2009 (in Norwegian).
- Homb, A. *Nedbøyning og vibrasjoner til bjelkelag (Deflections and vibrations of beam constructions)*. Project report SINTEF Byggforsk, serienr. 49, Oslo 2009 (in Norwegian).
- Homb, A., Hveem, S. *Lydoverføring i byggesystemer med massivtreelementer (Sound transmission in building constructions with cross laminated timber elements) .* Project report SINTEF Byggforsk, serienr. 80, Oslo 2011 (in Norwegian).

11 - RESEARCH ACTIVITIES AT THE UNIVERSITY OF CANTERBURY, CHRISTCHURCH NEW ZEALAND

Jeffrey Mahn

Relevant for WG1 and WG4

11.1 - Current research

- Sound transmission through roofing systems inclusive of the cladding, joists and ceiling. The purpose of the industry funded study is to determine the influence of the different components of the roofing system on the transmission of traffic and aircraft noise into a dwelling. The study will include both laboratory testing and field testing in a dedicated test house. The laboratory testing includes both the evaluation of the intensity sound reduction index of just the claddings and of the roofing system in compliance with ISO 15186-1. The study will also include the evaluation of prediction methods for the transmission of noise through roof systems and the sound reduction index of corrugated metal claddings. Project start May 2010 and planned stop April 2012.
- Prediction of the sound reduction index of corrugated panels based on laboratory measurements.
- Prediction of the sound reduction index of metal tiles based on laboratory measurements.
- Prediction of the sound reduction index of complete roof systems.
- Development of a new acoustics section of the New Zealand Building Code based on field testing rather than the laboratory testing of building elements.
- Development of a library of the acoustic properties of lightweight building elements for the approved solutions of the New Zealand Building Code.
- Sound transmission through facades.
- Evaluation of the calculation of the resonant component of the sound reduction index for use in the EN12354-1 standard for lightweight building elements.
- The uncertainty of the measured sound reduction index in the 1/3 octave bands below 100 Hz.

11.2 - Previous research

- PhD study on the application of EN12354-1 to lightweight building constructions.
- Evaluation of the uncertainty of the EN12354-1 method.

11.3 - Available papers / presentations

[1] Mahn, J. and Pearse, J., Uncertainty of the Direction-Averaged Velocity Level Difference, Proceedings of 15th International Conference on Sound and Vibration, Daejeon, Korea, 2008.

[2] Mahn, J. and Pearse, J., Reciprocity and the Prediction of the Apparent Sound Reduction Index for Lightweight Structures According to EN12354, Proceedings of Acoustics'08, Paris, 2008.

[3] Mahn, J. and Pearse, J., Separation of Resonant and Non-Resonant Components Part I: Sound Reduction Index, Building Acoustics, 2008, 15(2), 95-115.

[4] Mahn, J. and Stevenson, D. C., Separation of Resonant and Non-Resonant Components Part II: Surface Velocity, Building Acoustics, 2008, 15(2), 117-135.

[5] Mahn, J. and Pearse, J., On the Probability Density Functions of the Terms Described by the EN12354 Prediction Method, Building Acoustics, 2008, 15(4), 263-287.

[6] Mahn, J. and Pearse, J., The Probability Density Functions and the Uncertainty of the EN12354 Prediction Method, Proceedings of Inter-Noise 2008, Shanghai China, 2008.

[7] Mahn, J., Prediction of Flanking Noise Transmission in Lightweight Building Constructions: A Theoretical and Experimental Evaluation of the Application of EN12354-1, PhD Thesis, University of Canterbury, 2009.

[8] Mahn, J. and Pearse, J., The Propagated Uncertainty of EN12354-1 for Lightweight Building Constructions, Proceedings of Inter-Noise, Ottawa, Canada, 2009.

Abstract

This paper describes the calculation of the uncertainty of the EN12354 estimate of the flanking sound reduction index due to the uncertainty of the input data. The propagated uncertainty was derived using the method described by the ISO Guide to the Expression of Uncertainty in Measurement (GUM). The number of effective degrees of freedom was also derived so that the confidence intervals of the EN12354 estimate may be calculated. The propagated uncertainty of the EN12354 estimate of the flanking sound reduction index of lightweight constructions is shown to be dependent on the uncertainty of the calculated resonant component of the sound reduction index of the elements and the variance of the surface velocity measured on the elements according to ISO10848-1. Lightweight constructions which may not support diffuse vibratory fields will result in a larger propagated uncertainty of the EN12354 estimate than elements which do support diffuse vibratory fields.

[9] Mahn, J. and Pearse, J., On the Uncertainty of the EN12354-1 Estimate of the Flanking Sound Reduction Index Due to the Uncertainty of the Input Data, Building Acoustics, 2009, 16(3), 199-231.

Abstract

Equations to calculate the uncertainty of the EN12354-1 estimate of the flanking sound reduction index due to the uncertainty of the input data are derived using the method of the ISO Guide to the Expression of Uncertainty in Measurement (GUM). The uncertainty equations have been validated using Monte Carlo

simulations. It is shown that the magnitude of the uncertainty depends on the uncertainty of the resonant sound reduction indices of the elements, the uncertainty of the vibration reduction index and the uncertainty of the equivalent absorption lengths and areas of the elements. However, equations could not be derived to calculate the uncertainty of the EN12354 estimate of the apparent sound reduction index which has a log-normal probability density function and is therefore outside of the scope of the method of GUM. Monte Carlo simulations must be used to calculate the uncertainty of the apparent sound reduction index. It is recommended that guidance for calculating and declaring the uncertainty is included in future versions of EN12354, ISO10848 and ISO15712.

[10] Mahn, J. and Pearse, J., Evaluation of the EN12354 Method through Field Testing Using Sound Intensity, Proceedings of Inter-Noise, Lisbon, Portugal, 2010.

Abstract

The accuracy of the EN12354 method of predicting the apparent sound reduction index in building constructions which include lightweight elements was evaluated through field testing. This evaluation differed from most prior studies because the intensity sound reduction index of each of the flanking elements in the receiving room was measured in addition to the apparent sound reduction index. The measurement of the intensity flanking sound reduction index allowed for the assessment of the EN12354 prediction of the flanking sound reduction index of each element in the source room. The study found that the use of the apparent sound reduction index alone was not sufficient to evaluate the accuracy of the EN12354 predictions. Sound intensity measurements were needed to fully evaluate the accuracy of the predictions. The use of sound intensity is a promising method to evaluate future changes to the EN12354 method for application to lightweight building constructions.

[11] Mahn, J. and Pearse, J., Evaluation of the Sound Insulation of Roofing Systems, Proceedings of Twentieth International Congress on Acoustics (ICA 2010), Sydney, Australia, 2010.

Abstract

The transmission of noise from the outside environment into dwellings is often a concern for the inhabitants. However, the transmission of the noise through the roof is often overlooked when the sound insulation of the dwelling is being assessed unless the dwelling is located near an airport. The transmission of noise through the roof system depends not only on the performance of the roof cladding, but also on the structure-borne noise attenuation of the trusses, the ceiling and the ceiling insulation. In this investigation, the sound insulation of different configurations of roofing systems were evaluated in the laboratory. The configurations tested included variations in the cladding, the sarking installed under the cladding, the thickness of the insulation installed between the ceiling joists and the ceiling construction. The outcome of the study will help to improve the acoustic performance of roofing systems as well as to assist architects in the selection of roofing systems.

[12] Mahn, J., Davy, J. L., and Pearse, J., The Acoustic Requirements of Dwellings in New Zealand, Proceedings of Forum Acusticum 2011, Aalborg, Denmark, 2011.

Abstract

With a growing number of New Zealanders living in medium and higher density housing, it has become important to ensure that household units have appropriate levels of noise insulation. Revisions to the New Zealand Building Code Clause G6 - Protection from Noise are currently under consideration by the New Zealand Department of Building and Housing. The revisions to the Building Code mark a shift from laboratory based testing to field testing for compliance. In this paper, the current and the proposed sound insulation requirements in New Zealand as well as the requirements in Australia are compared to the requirements currently in use in Europe. The paths to compliance in New Zealand are also examined including the proposed database of acceptable construction solutions to meet the new regulatory requirements.

[13] Mahn, J. and Pearse, J., The Sound Insulation of Lightweight Roofing Systems, Proceedings of Inter-Noise 2011, Osaka, Japan, 2011.

Abstract

The transmission of noise from the outside environment into dwellings is often a concern when the dwellings are to be built in an area where background noise levels are an issue. A transmission path which is often overlooked during the planning phase unless the dwelling is near an airport is that through the roof system inclusive of the cladding, the trusses, the ceiling insulation and the ceiling. Little is currently known or published about the sound reduction index of the claddings or the lightweight roof systems commonly used in New Zealand. In this investigation, the intensity sound reduction indices of different configurations of lightweight roofing systems were measured in the laboratory. The configurations evaluated included variations in the cladding, the underlay installed under the cladding, the thickness of the thermal insulation above the ceiling and the ceiling plasterboard. The outcome of the evaluation will assist in the selection of the optimal roofing system for dwellings built where the outside noise levels are a concern.

[14] Mahn, J., "Evaluation of the Methods to Calculate the Resonant Sound Reduction Index," COST Action FP0702, Zurich, Switzerland, Report WG1-N23, 2011.

Abstract

The methods of calculating the resonant sound reduction index which were presented in WG1-N19 are evaluated by comparing predictions of the flanking sound reduction index measured values for single and double leaf panels. The CSTB Correction factor and the CSTB Method are shown to result in the best predictions for the double leaf and single leaf panels, respectively.

[15] Mahn, J. and Pearse, J., Revising the EN12354 Method of Calculating the Flanking Sound Reduction Index of Lightweight Building Elements, Proceedings of Acoustics 2012 Hong Kong, Hong Kong, 2012.

Abstract

There is great interest worldwide in using the standard, EN12354 to predict the flanking sound reduction index of lightweight building constructions. However, there are several problems which must be overcome before the prediction method can be accurately applied to lightweight building elements. One problem is that the resonant component of the sound reduction index of lightweight elements must typically be determined for the predictions. Three methods of determining the resonant component which are being considered by COST Action FP0702 have been evaluated. The evaluation was conducted by comparing the predicted flanking sound reduction indices which were calculated using the different methods of calculating the resonant sound reduction index to the measured flanking intensity sound reduction index for a series of elements. The elements included single, homogeneous elements and double leaf elements. The determination of the resonant sound reduction index using a correction factor proposed by CSTB based on the radiation efficiencies of the elements is recommended.

[16] Mahn, J. and Pearse, J., The Calculation of the Resonant Sound Reduction Index for Use in EN12354, Proceedings of Euronoise 2012, Prague, Czech Republic, 2012.

Abstract

Lightweight constructions typically have critical frequencies in or above the frequency range of interest. Since EN12354 only considers resonant transmission for the calculation of the flanking sound reduction

index, the resonant component of the sound reduction indices used in the predictions must be calculated theoretically or from measurement data. Several methods of calculating the resonant sound reduction index have been proposed with several being considered by the COST Action FP0702. These methods include Method Gerretsen, Method CSTB and the CSTB correction factor. This paper evaluates the proposed methods of calculating the resonant sound reduction index by comparing the flanking sound reduction index predicted using the different resonant sound reduction indices to measured data.

12 - RESEARCH ACTIVITIES AT RMIT AND CSIRO, AUSTRALIA

John Davy

Relevant for WG1

12.1 - Current research

1. Prediction of flanking transmission below the critical frequency.
2. Prediction of the directivity of sound insulation.
3. Prediction of the direct sound transmission of single walls and cavity walls.
4. Prediction of the direct sound insulation of steel stud walls and walls with resilient furring channels

12.2 - Available publications

[1] Davy, J.L. (2009). Predicting the sound insulation of walls. Journal of Building Acoustics 16(1):1-20. doi:10.1260/135101009788066546 .

Abstract

Between 1990 and 1998, the author published five conference papers which described the gradual development of a simple theoretical model for predicting the sound insulation of building partitions. The first aim was to extend Sharp's model for cavity walls to cavities without sound absorption. The second aim was to remove the reported over prediction of Sharp's model for cavity walls. The third aim was to explain the five decibel empirical correction in Sharp's model for stud walls. The fourth aim was to produce a more theoretically valid model than Gu and Wang's steel stud wall model. Although the simple theoretical model has been reasonably successful, several concerns have since arisen. This paper describes how these concerns have been addressed and gives the current version of this theoretical model for predicting sound insulation. The theoretical model is compared with a number of experimental measurements and produces reasonable agreement.

[2] Davy, J.L. (2009). The directivity of the sound radiation from panels and openings. Journal of the Acoustical Society of America 125(6):3795-3805. doi:10.1121/1.3117687 .

Abstract

This paper presents a method for calculating the directivity of the radiation of sound from a panel or opening, whose vibration is forced by the incidence of sound from the other side. The directivity of the radiation depends on the angular distribution of the incident sound energy in the room or duct in whose wall or end the panel or opening occurs. The angular distribution of the incident sound energy is predicted using a model which depends on the sound absorption coefficient of the room or duct surfaces. If the sound source is situated in the room or duct, the sound absorption coefficient model is used in conjunction with a model for the directivity of the sound source. For angles of radiation approaching 90 ° to the normal to the panel or opening, the effect of the diffraction by the panel or opening, or by the finite baffle in which the panel or opening is mounted, is included. A simple empirical model is developed to predict the diffraction of sound into the shadow zone when the angle of radiation is greater than 90 ° to the normal to the panel or opening. The method is compared with published experimental results.

[3] Davy, J.L. (2009). The forced radiation efficiency of finite size flat panels which are excited by incident sound. Journal of the Acoustical Society of America 126(2):694-702. doi:10.1121/1.3158820 .

Abstract

The radiation efficiency of an infinite flat panel which is radiating a plane wave into a half space is equal to the inverse of the cosine of the angle between the direction of propagation of the plane wave and the normal to the panel. The fact that this radiation efficiency tends to infinity as the angle tends to 90 ° causes problems with simple theories of sound insulation. Sato has calculated numerical values of radiation efficiency for a finite size rectangular panel in an infinite baffle whose motion is forced by sound incident at an angle to the normal from the other side. This paper presents a simple two dimensional analytic strip theory which agrees reasonably well with Sato's numerical calculations for a rectangular panel. This leads to the conclusion that it is mainly the length of the panel in the direction of radiation, rather than its width that is important in determining its radiation efficiency. A low frequency correction is added to the analytic strip theory. The theory is analytically integrated over all angles of incidence, with the appropriate weighting function, to obtain the diffuse sound field forced radiation efficiency of a panel.

[4.] Davy, J.L. (2009). Predicting the sound insulation of single leaf walls - extension of Cremer's model. Journal of the Acoustical Society of America 126(4):1871-1877. doi:10.1121/1.3206582 .

Abstract

In his 1942 paper on the sound insulation of single leaf walls, Cremer made a number of approximations in order to show the general trend of sound insulation above the critical frequency. Cremer realised that these approximations limited the application of his theory to frequencies greater than twice the critical frequency. This paper removes most of Cremer's approximations so that the revised theory can be used down to the critical frequency. The revised theory is used as a correction to the diffuse field limp panel mass law below the critical frequency by setting the nonexistent coincidence angle to ninety degrees. The diffuse field limp panel mass law for a finite size wall is derived without recourse to a limiting angle by following the average diffuse field single sided radiation efficiency approach. The shear wave correction derived by Heckl and Donner is applied to the revised theory in order to cover the case of thicker walls. The revised theory predicts the general trend of the experimental data, although the agreement is usually worse at low frequencies and depends on the value of damping loss factor used in the region of and above the critical frequency.

[5] Davy, J.L. (2010). The improvement of a simple theoretical model for the prediction of the sound insulation of double leaf walls. Journal of the Acoustical Society of America 127(2):841-849. doi:10.1121/1.3273889 .

Abstract

This paper presents a revised theory for predicting the sound insulation of double leaf cavity walls that removes an approximation which is usually made when deriving the sound insulation of a double leaf cavity wall above the critical frequencies of the wall leaves due to the airborne transmission across the wall cavity. This revised theory is also used as a correction below the critical frequencies of the wall leaves instead of a correction due to Sewell [(1970). J. Sound Vib. 12, 21-32]. It is found necessary to include the "stud" borne transmission of the window frames when modelling wide air gap double glazed windows. A minimum value of stud transmission is introduced for use with resilient connections like steel studs. Empirical equations are derived for predicting the effective sound absorption coefficient of wall cavities without sound absorbing material. The theory is compared with experimental results for double glazed windows and gypsum plasterboard cavity walls with and without sound absorbing material in their

cavities. The overall mean, standard deviation, maximum and minimum of the differences between experiment and theory are -0.6 dB, 3.1 dB, 10.9 dB at 1250 Hz and – 14.9 dB at 160 Hz respectively.

[6] Davy, J. L., Guigou-Carter, C., and Villot, M. (2010). The equivalent translational stiffness of steel studs. Proceedings of 20th International Congress on Acoustics, ICA 2010, 23-27 August 2010, Sydney, Australia, Paper No. 21, edited by Burgess, M., Davy, J., Don, C. and McMinn, T., refereed conference paper only available on CD-ROM, ISBN: 978-0-646-54052-8.

Abstract

The effect of the resilience of the steel studs on the sound insulation of steel stud cavity walls can be modelled as an equivalent translational stiffness in simple models for predicting the sound insulation of walls. Numerical calculations (Poblet-Puig et al., 2009) have shown that this equivalent translational stiffness varies with frequency. Vigran (2010a) has derived a best-fit third order polynomial approximation to the logarithm of these numerical values as a function of the logarithm of the frequency for the most common type of steel stud. This paper uses an inverse ex-perimental technique. It determines the values of the equivalent translational stiffness of steel studs which make Davy's (2010) sound insulation theory agree best with experimental sound insulation data from the National Research Council of Canada (NRCC) (Halliwell et al., 1998) for 126 steel stud cavity walls with gypsum plasterboard on each side of the steel studs and sound absorbing material in the wall cavity. These values are approximately constant as a function of frequency up to 400 Hz. Above 400 Hz they increase approximately as a non-integer power of the fre-quency. The equivalent translational stiffness also depends on the mass per unit surface area of the cladding on each side of the steel studs and on the width of the steel studs. Above 400 Hz, this stiffness also depends on the stud spac-ing. The equivalent translational stiffness of steel studs determined in this paper and the best-fit approximation to that data are compared with that determined numerically by Poblet-Puig et al. (2009) and with Vigran's (2010a) best-fit approximation as a function of frequency. The best-fit approximation to the inversely experimentally determined values of equivalent translational stiffness are used with Davy's (2010) sound insulation prediction model to predict the sound insulation of steel stud cavity walls whose sound insulation has been determined experimentally by NRCC (Halliwell et al., 1998) or CSTB (Guigou-Carter and Villot, 2006).

[7] Davy, J. L., Guigou-Carter, C., and Villot, M. (201X). An empirical model for the equivalent translational compliance of steel studs. Submitted to Journal of the Acoustical Society of America on 10 May 2010. Revised version submitted on 4 September 2011. Being refereed.

Abstract

The effect of the resilience of the steel studs on the sound insulation of steel stud cavity walls can be modelled as an equivalent translational compliance in simple models for predicting the sound insulation of walls. Recent numerical calculations have shown that this equivalent translational compliance varies with frequency. This paper determines the values of the equivalent translational compliance of steel studs which make a simple sound insulation theory agree best with experimental sound insulation data for 126 steel stud cavity walls with gypsum plaster board on each side of the steel studs and sound absorbing material in the wall cavity. These values are approximately constant as a function of frequency up to 400 Hz. Above 400 Hz they decrease approximately as a non-integer power of the frequency. The equivalent translational compliance also depends on the mass per unit surface area of the cladding on each side of the steel studs and on the width of the steel studs. Above 400 Hz, this compliance also depends on the stud spacing. The best fit approximation is used with a simple sound insulation prediction model to predict

the sound insulation of steel stud cavity walls whose sound insulation has been determined experimentally.

[8] Davy, J. L., Mahn, J., Guigou-Carter, C., and Villot, M. (201X). The prediction of flanking sound transmission below the critical frequency. Submitted to the Journal of the Acoustical Society of America on 29 July 2011. Revised version submitted on 9 January 2012. Being refereed.

Abstract

Although reliable methods exist to predict the apparent sound reduction index of heavy, homogeneous isotopic building constructions, these methods are not appropriate for use with lightweight building constructions which typically have critical frequencies in or above the frequency range of interest. Three main methods have been proposed for extending the prediction of flanking sound transmission to frequencies below the critical frequency. The first method is the direct prediction which draws on a database of measurements of the flanking transmission of individual flanking paths. The second method would be a modification of the existing EN 12354 (ISO 15712) standard. This method requires the calculation of the resonant sound transmission factors. However, most of the approaches proposed to calculate the resonant sound transmission factor work only for the case of single leaf homogeneous isotropic building elements and therefore are not readily applicable to complex building elements. The third method is the measurement or prediction of the resonant radiation efficiency and the airborne diffuse field excited radiation efficiency which includes both the resonant and the non-resonant radiation efficiencies. The third method can currently deal with complex building elements if the radiation efficiencies can be measured or predicted. This paper examines these prediction methods.

13 - RESEARCH ACTIVITIES AT NTNU, TRONDHEIM, NORWAY

Nathalie Labonnote

Relevant for WG2

13.1 - Previous research

Validation of an experimental protocol to evaluate damping

- ***Experimental protocols***

The driving point method estimates the fundamental frequencies and the associated damping ratios from one single impact, whereas the roving hammer method estimates the mode shapes, and the associated fundamental frequencies and damping ratios from several impacts located on a selected mesh on the structure. For both methods, transient accelerations due to modal hammer impact are processed in order to build the Frequency Response Function (FRF). Experimental modal analysis is then used to curve fit an analytical FRF, from which the dynamic characteristics of the structure are estimated.

- ***Investigation of consistency and robustness***

Repeatability and reproducibility were studied using a panel of 10 operators. Parametric studies were conducted in order to check the reciprocity principle. It was concluded that the method provides reliable damping ratio evaluations, which do not depend on strength or skills of the operator.

- ***Experimental evaluations of material damping***

Timber beam specimens were subjected to flexural vibrations through the impact test method described in section 2. The material damping was evaluated in 11 solid wood beams and 11 glulam beams, both types made out of Norway Spruce, whose cross-sections were representative of common timber floor structures. The beams were simply supported with a symmetric overhang, and were tested at different spans and orientations. A total of 420 material damping evaluations were performed. The results are presented as mean values for each configuration along with important statistical indicators to quantify their reliability.

13.2 - Current research

13.2.1 - Analytical prediction of material damping

Complex elastic moduli and complex global stiffness were defined to derive a relationship between the equivalent viscous damping for the whole structure (which is a system quantity depending on the boundary conditions) and the bending and shear damping parameters and (which are intrinsic material properties). Physical interpretations of the derived model were given, and the different contributions from shear and pure bending were discussed. Shear damping and bending damping were defined accordingly. Fitting of the model was performed using the experimental results described in section 3.1. The good agreement of the derived model with experimental data reveals an efficient approach to the prediction of internal damping.

13.2.2 - Measurement and prediction of material damping in sheathing panels

The same protocol is currently being applied to different types of wooden panels. Damping is evaluated through the impact method for isotropic timber panels (fiberboard panels), transversely isotropic timber panels (OSB panels), and orthotropic timber panels (Structural LVL). Three different boundary conditions and two different thicknesses are investigated for each type of panel. A similar derivation as in section 3.2, extended to various plate theories, is currently being developed to predict material damping in wood sheathing panels.

13.3 - Planned research

Experimental evaluations of damping are intended to be performed first in assemblies formed by two timber beams (joists) and sheathing panels, and then to complete portion of floors. From the joist/sheathing panel experimental data, it is expected that the damping due to connectors is evaluated and discussed. From the complete section of floor, it is expected that the damping due to friction in-between components is evaluated and discussed. Prediction models for both connector damping and friction damping are expected to be developed.

14 - RESEARCH ACTIVITIES AT FCBA

Jean-Luc Kouyoumji

For WG1 and partly WG4

14.1 - Current research

- Bois-AcouTherm Collaborative Project with FCBA, InterAC, EFIA, Finnforest, ISOVER, Bouygues.: Acoustic – Thermal Interaction in lightweight constructions. Testing and predicting new generation of timber buildups, when design is controlled by Building Energy Efficiency. Database of about 110 tested configurations of wall, floors and roofs. Creation of SEA-Wood a design tool for timber building acoustics. Predicting walls and junctions' behavior, see papers 1, 2 & 6.
- Prediction and in-situ measurement of usual wall in zero-energy timber buildings.
- Collaborative project with FCBA and FPInnovations Canada, Acoustics of Cross Laminated Timber floors, see papers 2 & 3, and presentations.
- PhD-study on Objective and subjective qualification of acoustic and thermal comfort in timber framed houses, Sylvain Boulet, 2006-2010. Paper 4.
- Silent Wall : observation, description and modelling of heterogeneity, physical model development, design and elaboration of material, experimental validation, and optimisation, 2006-2011.
- Acoubois project: partners: CSTB, FCBA and QUALITEL; financially supported by DHUP, CODIFAB (wood manufacturer organization), the wood industry, and the building industry. Phase 1 of the project in 2010: gathering and categorizing the different building elements and junctions between elements used in France in timber based lightweight buildings; identification of missing data.

14.2 - Previous research

- PhD-study on "Characterization of lightweight walls and junctions for acoustical prediction of timber construction", Jean-Luc Kouyoumji; 1997-2000; see various papers and thesis,
- Two Projects on "Panacoustique : Characterization panels and timber walls", 2001-2006,
- Collaborative project "Acoustics of flooring" FCBA, CSTB, CEBTP and Flooring industry, 2001-2004
- Other projects on wooden windows, stairs, floors, walls, since 1997,
- Various consultancy projects on acoustics of lightweight buildings,

14.3 - Available papers / presentations

[4] Kouyoumji J.L, Borello G., Vernois L., Prediction of Flanking Transmission in light weight timber framed construction with SEA-Wood, a SEA software 40th Internoise Congress, September 4-7, 2011, Osaka, Japan.

[5] Kouyoumji J.L., Gagnon S., Experimental approach on sound transmission loss of, Cross Laminated Timber floors for building, 39th Internoise International Congress, June 13-16, 2010, Lisbon, Portugal.

[6] Kouyoumji J.L., Gagnon S., Boulet S., Sound transmission loss of Cross Laminated Timber 'CLT'floors, measurements and modelling using SEA. 38th Internoise International Congress, 23-26 August 2009, Ottawa, Canada.

[7] Boulet S., Kouyoumji J.L., Achard G., Objective and subjective qualification of acoustic and thermal comfort in timber framed houses, 38th Internoise International Congress, 23-26 August 2009, Ottawa, Canada.

[8] Kouyoumji J.L., Borello G, Thibier E, Sound transmission loss of timber constructions, measurements and modeling using SEA-Wood©, a Statistical Energy Analysis software for light weight constructions. 37th Internoise International Congress, 26-29 October 2008, Shanghai, China.

[9] Kouyoumji J.L., Vibro-Acoustics characterization of timber constructions: measurements and modeling using Statistical Energy Analysis (SEA) 36th Internoise, 28-31 august 2007 Istanbul, Turkey.

[10] Kouyoumji J.L., Sub-structuring of timber construction and prediction of flanking transmission using SEA and reverse SEA. 35th Internoise, 3-6 december 2006, Honolulu, Hawaii, USA

[11] Kouyoumji J.L., L.Vernois, Experimental and analytic study about non- homogeneous plate sound transmission loss. 35th Internoise, 3-6 december 2006, Honolulu, Hawaii, USA

[12] Kouyoumji J.L., Achard G., Reverse SEA used for characterization and prediction of flanking transmission in timber light weight construction. 2nd International Symposium on advanced Timber and Timber-Composite Elements for Buildings. Acoustic performance and low frequency vibration. 27 April 2006. Biel – Switzerland

[13] Kouyoumji J.L., Reverse SEA used for characterization and prediction of flanking transmission in timber light weight construction. 34th Internoise, Rio, Brazil, 2005

[14] Kouyoumji J.L., Borello G., Vibroacoustic analysis of sound transmission in double-glass timber windows. 34th Internoise, Rio, Brazil, 2005

[15] Kouyoumji J.L., Guigou-Carter C, Villot M, Analytical and experimental study of wood floorings. 34th Internoise, Rio, Brazil, 2005

[16] Kouyoumji J.L., Borello G., Vibroacoustic analysis of sound transmission in double-glass timber windows. 34th Internoise, Rio, Brazil, 2005

[17] Kouyoumji J.L., Vernois L., An exploratory study about taking into account heterogeneity of a material in the calculation of it's sound transmission loss. 34th Internoise, Rio, Brazil, 2005

[18] Kouyoumji J.L. Sound transmission loss prediction and vibro-acoustic SEA analysis of a wood framed floor Proc. 33rd Internoise, Prague, Czech Republic, 2004.

[19] Kouyoumji J.L. Caractérisation des parois courantes et des liaisons structurales pour la prévision de l'isolement acoustique d'une construction en bois, thèse de l'Université de Savoie LGCH-ESIGEC, soutenue le 15 décembre 2000, 185 pp.

15 - RESEARCH ACTIVITIES AT THE CENTRE FOR TIMBER ENGINEERING, EDINBURGH NAPIER UNIVERSITY, EDINBURGH, UK

Binsheng Zhang

For WG3

15.1 - Current research

- Tall Timber Buildings: This is a joint research initiative with Bath University, Strathclyde University and Edinburgh University. This project aims to bring the UK's timber research community together with apposite expertise in a whole systems approach to address the structural engineering challenge of constructing safe and serviceable timber buildings over 30 stories high within the next 15-20 years. One of the many objectives for this project is to develop building forms and optimum structural arrangements and solutions needed to achieve safe and serviceable timber structures 30-45 stories high. Focusing on strategies for dynamic building responses under both service and ultimate wind loading, this will be achieved through structural modelling using non-linear structural finite element method, large-scale testing and monitoring of real structures. Solutions for dealing with structural movements and seismic loadings using quantifiable performance based metrics are also considered.
- Investigations of dynamic performance of attic room floors in timber framed houses: This project allows using commercial finite element software to analyse the dynamic performance of the flooring systems in the attic room of duo-pitch timber frame houses. The vibrational serviceability parameters include the mid-span deflections of the bottom chord under dead loads and unit point load and the modal frequencies and shapes. The influence of geometric configurations is systematically studied, including bracing members, floor span and roof pitch angle. The composite effect is also to be investigated. Thus, a design equation for predicting the fundamental frequency can be proposed.
- Engineered timber wall panels subjected to combined vertical and lateral loading: This PhD project allows engineered timber wall panels being subjected to lateral loading together with varied vertical loading until failure to examine the performance of these panels under service and ultimate loading. The dynamic and acoustic performance of the wall panels will be looked into in later stage.
- UK National Annexes to Eurocode 5: The centre has been largely involved in the UK timber design committee for the development of UK National Annexes and other technical documents to Eurocode 5 and much research work has been included in the design codes.

- Consultant work on testing timber materials, members and structures and designing timber structures on static, dynamic and acoustic performance.

15.2 - Previous research

- PhD study on "Dynamic response of structural timber flooring systems", Jan Weckendorf; 2005-2009; see various papers and thesis.
- PhD study on "Development and evaluation of composite insulated beams", Ali Bahadori Jahromi; 2002-2005; see various papers and thesis.
- Project on "Testing to Evaluate the Vibration/Deflection of Metal Web Joist Floors & the Enhanced Floor Flexural Rigidity by the Introduction of Strongback Bracing", collaborated with the Metal Web Working Group comprising ITW Alpine, Gang Nail Systems, MiTek Industries Ltd and Wolf Systems., 2008.
- CPD courses to practical engineers on the design of timber structures to Eurocodes.
- Various consultant projects on testing timber materials, members and structures, and carrying out design of timber structures, since 2003.

15.3 - Available papers / presentations

[1] Zhang B. Comparison of vibrational serviceability criteria for design of timber floors among European countries, The World Conference on Timber Engineering – 2012 (WCTE-2012), Auckland, New Zealand, July 2012.

[2] Zhang B. and Bastien C. Dynamic performance of attic rooms in duo-pitch timber frame houses, The World Conference on Timber Engineering – 2012 (WCTE-2012), Auckland, New Zealand, July 2012.

[3] Zhang B., Weckendorf J. and Kermani A. Vibrational performance of metal-webbed timber floors, The 11th World Conference on Timber Engineering (WCTE-11), Riva del Garda, Trentino, Italy, June 2010.

[4] Weckendorf J., Zhang B., Kermani A. and Reid D. Finite element modelling of I-joist timber flooring systems to predict modal frequencies, modal shapes and static point load deflections, The 11th World Conference on Timber Engineering (WCTE-11), Riva del Garda, Trentino, Italy, June 2010.

[5] Weckendorf J. Dynamic response of structural timber flooring systems. PhD thesis. Edinburgh Napier University, Edinburgh, UK, 2009.

[6] Weckendorf J., Zhang B., Kermani A. and Reid D. Damping characteristics of timber flooring systems, The 10th World Conference on Timber Engineering (WCTE-10), Miyazaki, Japan, June 2008.

[7] Weckendorf J., Zhang B., Kermani A. and Reid D. Effects of mass and local stiffening on the dynamic performance of timber floors, The 10th World Conference on Timber Engineering (WCTE-10), Miyazaki, Japan, June 2008.

[8] McKenzie W.M.C. and Zhang B. Design of Structural Timber to Eurocode 5, Palgrave MacMillan, Basingstoke, UK, Sept 2007, ISBN: 978-0230-00777 2, 508 pp.

[9] Bahadori-Jahromi A., Kermani A. and Zhang B. A parametric evaluation of the multi-webbed composite joists based on EC5, Journal of the Institute of Wood Science, 2007.

[10] Bahadori-Jahromi A., Zhang B., Harte A., Walford B., Bayne K. and Turner J. Investigating the structural performance of multi-webs I-beams, Journal of the Institute of Wood Science, 17(3), 148-158, 2006.

[11] Bahadori-Jahromi A., Kermani A., Zhang B., Harte A., Walford B., Bayne K. and Turner J. Influence of geometrical profiles on the structural properties of engineered composite timber beams, Proceedings of the Institution of Civil Engineers, Journal of Buildings & Structures, 159(SB2), 103-114, 2006.

[12] Weckendorf J., Zhang B., Kermani A., Dodyk R. and Reid D. Assessment of vibrational performance of timber floors, The 9th World Conference on Timber Engineering (WCTE-9), Portland, Oregon, USA, 2006.

[13] Zhang B, Bahadori-Jahromi A, Kermani A. Influence of EC5 and the UK National Annex on the design of timber flooring systems built with multi-webbed engineered joists and solid timber joists. Technical document for BSI Technical Committee B/525/5, BSI, UK, 2005.

[14] Zhang B. Parametric study on the design of timber floor joists to Eurocode 5 and UK National Annex. Technical document for BSI Technical Committee B/525/5, BSI, UK, 2004.