Forintek Canada Corp.

Project No. 2691

Canadian Forest Service No. 13

Plan a Research Program for Acoustic Performance of Wood-frame Buildings

by

Lin J. Hu
Research Scientist
Building Systems Department

March 2001

This project was financially supported by the Canadian Forest Service under the Contribution Agreement existing between the Government of Canada and Forintek Canada Corp.

Project Leader

Reviewed by

Department Manager

Abstract

Acoustic performance is one of the important issues that need to be addressed to help wood compete with other materials in the housing market, especially the multi-family housing market. The 1995 National Building Code of Canada (NBCC) increased the minimum sound transmission class (STC) ratings requirement from 45 to 50 between residential suites, and from 50 to 55 between suites and vertical shafts, against the 1990 NBCC. In a recent survey of prefabricated houses, sound performance was reported to be a key concern for increased acceptance of wood-frame buildings components in foreign markets, particularly Europe and Japan, where the code requirements for sound insulation are more stringent than in Canada. In view of this growing awareness of acoustic performance issues in Canada and elsewhere, and the corresponding evolution of building codes, the wood industry needs to demonstrate that wood-frame buildings can match or outperform buildings using other materials with respect to all major criteria, including acoustic performance.

This report proposes a research plan to address the sound transmission issues raised specifically in connection with wood-frame buildings. These issues are not completely addressed or understood, or they have been ignored by non-wood researchers or the current National Building Code of Canada. The issues identified include: 1) a lack of design information on Field Sound Transmission Class (FSTC) and Impact Insulation Class (FIIC) ratings for wood-frame construction; 2) conflicts between some construction solutions for sound insulation and other performance attributes; 3) a lack of design and construction guidelines for low frequency thumping noises induced by footsteps in wood-frame construction; 4) limited information on the design of wood-frame construction insulated against exterior noises. Forintek lacks the expertise to deal with noise insulation issues in wood-frame construction.

A research program consisting of four projects is proposed to address these issues. It is recommended that Forintek should play an active role in sound insulation research and build up its expertise in order to deal with occupant complaints about poor sound performance in wood-frame buildings. The expertise needed includes technology for in-situ problem solving, field measurement techniques and systems, a computer model to predict the sound performance of wood-frame systems, design solutions for low frequency thumping noises, and retrofit techniques.

Co-ordination with acoustics experts at the Institute for Research in Construction (IRC) and other institutes, the wood and building industries, and code regulators is necessary to the success of this research program which will reinforce the performance attributes of Canadian wood-frame systems and increase their market acceptance.

Acknowledgements

Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), and the Provinces of British Columbia, Alberta, Quebec, Nova Scotia, New Brunswick and Saskatchewan for their guidance and financial support for this research.

The author wishes to thank members from the wood and building industries for their advice, guidance and support throughout the research described in this report.

Table of Contents

Abstract ii

Acknowledgements iii

1 Objectives 1

2 Introduction 1

3 Background 2
- 3.1 Requirements for Sound Insulation in NBCC 2
- 3.2 IRC Projects on Sound Performance and Flanking Transmission 2
- 3.3 Unresolved Issues and Research Needs 2
  - 3.3.1 Lack of Design Information on Field STC and IIC including the Effects of Flanking Transmission 2
  - 3.3.2 Sound Insulation Design Solutions Conflicting with Other Performance Requirements 3
  - 3.3.3 Lack of Design and Construction Guidelines for Low Frequency Thumping Noises Induced by Footsteps in Wood-based Floors 4
  - 3.3.4 Limited Information on Wood-frame Construction Design for Insulation from Exterior Noise Sources 5

4 Proposed Research Plan 6
- 4.1 Project on Resolving Design Conflicts Between Sound Performance and Other Performance Requirements 6
- 4.2 Project on Development of Design Information on Field Sound Performance of Wood-frame Construction 6
- 4.3 Project on Investigation of Thumping Noise in Wood-based Floors: Significance, Mechanism, Cause, and Solutions 7
- 4.4 Project on Wood-frame Construction Insulated from Exterior Noises 7

5 Co-ordination 8

6 References 8

1 Objectives

The objective of this report is to propose a research plan to address the sound-transmission issues raised specifically in relation to wood-frame buildings.

2 Introduction

To compete with the steel and concrete industries for the housing market, especially for the multi-family housing market, acoustic performance in wood-frame buildings is one of the important issues to address. The 1995 National Building Code of Canada (NBCC) increased the minimum sound-transmission-class (STC) ratings required from 45 to 50 between residential suites and from 50 to 55 between suites and vertical shafts, compared to the 1990 NBCC. In a recent survey of prefabricated houses, sound performance was reported to be a key concern for increased acceptance of wood-frame building materials in foreign markets, particularly in Europe and Japan, where code requirements for sound insulation are more stringent than in Canada. The growing concern over sound transmission in Canada and elsewhere, and the evolving building codes drive the wood industry to work towards increased market acceptance for wood-frame construction by demonstrating that it can be equal to or better than other materials in terms of acoustic performance.

The sound insulation of structures covers a vast area that includes current and expected codes, sound-performance ratings, laboratory measurement methods and systems, field measurement methods and systems, modelling, and construction solutions for sound insulation. It is impossible and unnecessary for Forintek and the wood industry to address all these fields. But it is important for Forintek to address the sound insulation issues raised in particular connection with wood-frame construction, as they have not received proper attention from non-wood researchers, and to build up expertise in in-situ problem solving.

In the Background section, the report reviews sound insulation requirements in the National Building Code of Canada and on-going research work at the Institute for Research in Construction (IRC) and other institutes on the sound ratings for walls and floors in laboratories, as well as flanking noise transmission in buildings. Two cases of occupant complaints concerning low frequency thumping noises in wood-frame buildings are described. Four sound insulation issues specifically raised in connection with wood-frame construction are identified and discussed in details. It has been found that these wood-related issues are not completely addressed or understood, or they have been ignored or misrepresented by non-wood researchers or the current National Building Code of Canada.

A research program consisting of four projects is proposed to resolve these issues. The Research Plan section of the report provides detailed descriptions of objectives and approaches for each project.

The report finally makes recommendations as to the role Forintek should play to address acoustic issues on behalf of the Canadian wood industry.

3 Background

3.1 Requirements for Sound Insulation in NBCC

The National Building Code of Canada (NBCC) requires sound insulation between dwellings. The 1995 NBCC requires a minimum Sound-Transmission-Class (STC) rating (airborne sound) of 50 between residential suites and 55 between suites and vertical shafts (NBCC 1995). The NBCC also provides STC ratings for a list of floor and wall assemblies (NBCC 1995).

The NBCC does not recommend a minimum value of Impact Insulation Class (IIC) for dwellings. Some other jurisdictions require a minimum IIC of 55 (Bodlund 1985). Designers and research scientists often use an IIC of 55 as additional guideline for noise control in buildings (Warnock 1993).

3.2 IRC Projects on Sound Performance and Flanking Transmission

Since 1992, Forintek Canada Corp., the Canada Mortgage and Housing Corporation (CMHC), the wood industry and other interested groups have participated in an IRC research project on the fire and sound performance of floors and walls. Data have been generated for the STC values of a broad range of wall and floor assemblies, and for the IIC values of a broad range of floors in the IRC laboratory (Richardson and Batista, 2001). Such laboratory STC and IIC ratings are usually called apparent STC and IIC.

In practice, the sound insulation of a building is often degraded because of the existence of flanking paths such as joints between sub-structures, as pointed by Warnock (1993). Since 1993, IRC has conducted a project on flanking transmission at joints in multi-family dwellings (Richardson and Batista 2001; Nightingale and Halliwell 1997). Much information on the effects of various flanking paths on apparent STC and IIC ratings has been generated by the flanking project.

3.3 Unresolved Issues and Research Needs

3.3.1 Lack of Design Information on Field STC and IIC including the Effects of Flanking Transmission

Even if the two IRC projects have generated much information, this information has not provided designers with an easy way to determine the real (field) sound performance of wood-frame construction where flanking paths unavoidably exist. Therefore design information on actual (field) STC and IIC values accounting for the effects of flanking paths in wood-frame buildings needs to be developed on the basis of the data generated by the IRC projects.

3.3.2 Sound Insulation Design Solutions Conflicting with Other Performance Requirements

From a review of the IRC data on apparent STC and IIC ratings for a broad range of floor and wall assemblies, and of the information available on construction solutions to reduce flanking noise transmission in buildings, we discovered some basic relationships between the properties of the structure and sound performance. For example, measures adopted to stiffen a system will reduce its sound insulation. Adding mass to a system will improve its apparent STC rating. Softening the surface of an assembly will improve its apparent IIC rating.

When applying these relationships to construction design, we found that, in practice, some sound insulation solutions may conflict with other performance requirements. For example, according to these relationships, the more flexible a floor system, the better its sound performance. But it is well known that a floor with too much flexibility (i.e. insufficient stiffness) will provide poorer serviceability; its serviceability will be further degraded after a heavy mass such as a heavy concrete topping is added to it. Solutions to such conflicts need to be investigated through a systems approach.

As a first step in our investigation, we reviewed design solutions for improved sound performance in wood-based floors. Several conflicts were identified through Forintek's project on floor buildability (Hu 2001).

One significant conflict related to the addition of a cement-type topping over a wood-based sub-floor to improve sound performance. This type of topping significantly improved the apparent STC rating of the floor due to its significant mass, but its hard surface significantly reduced the floor's apparent IIC rating. We further found that, when such a heavy topping was added to a wood-based floor without adequate stiffness, the floor became bouncier due to reduced damping. As explained by Ungar (1992), damping relates to the dissipation of vibration energy. Damping comes form all the vibration energy absorbers such as construction materials, supports, joints and attachments between components and sub-structures. In comparison with a cement-type floor, a wood-based floor has more joints and more flexible connections between components, therefore more damping and better sound performance. As pointed out by Richardson and Batista (2001), "When acoustic performance is considered, and particularly impact-noise-transmission, wood-frame construction has an almost insurmountable advantage over heavy concrete". But this advantage has not been fully taken into consideration and exploited.

For example, we noticed that the use of wood materials as topping could provide a solution to this conflicting performance issue with cement-type topping. A preliminary study on the sound and serviceability of a wood-based floor topped with a ¾" OSB panel showed that the panel directly over the sub-floor of a wood floor improved its STC and IIC ratings (Richardson 2000). Undoubtedly, an additional wood panel over the sub-floor will increase floor strength and stiffness, and improve its serviceability. More data and evidence as well as a construction guide are needed to support the replacement of cement-type topping by wood panels.

Another significant conflict relating to sound insulation concerned the application of floating floors. There are many types of floating floors. In general they improve sound performance, especially IIC ratings. But, without careful consideration of design details, some floating floors can lead to more perceptible vibrations in a floor with adequate stiffness, as reported by Talja and Toratti (2000). The pros and cons of various types of floating floors need to be analysed before they are recommended as a promising construction solution.

3.3.3 Lack of Design and Construction Guidelines for Low Frequency Thumping Noises Induced by Footsteps in Wood-based Floors

During our field study on floor vibration performance across Canada, we received several complaints about poor sound performance related to low frequency thumping noises induced by footsteps in wood-based floors, even if the field STC and IIC ratings of these floors met code requirements. From the literature, we found no effective solution to retrofit these unsatisfactory floors, nor any design guidelines.

The current design guideline providing a 55 IIC threshold to control impact sound was established on the basis of a standard test method using a lightweight impact device. The frequency range of the impact sound generated by the device is above 125 Hz. Therefore, the current 55 IIC threshold can control the noise due to a lightweight impact source such as a heel impact on the floor surface. However, the impact noise due to footsteps is generally much heavier than the heel impact. A heavy impact noise can contain significant frequency components much lower than 125 Hz. To distinguish it from a lightweight impact noise, the impact noise due to heavy footsteps is called low frequency noise. Softer materials such as carpet can effectively attenuate high frequency noises, but not low frequency thumping noises (Warnock 1993).

To demonstrate the effect of low frequency thumping noises, two interesting cases of occupant complaints about the thumping noises are presented below.

<u>Case-1</u>:

This floor was located in an expensive single-family house. The builder was also the owner and had a lot of knowledge about bouncy floors. To avoid springiness, he designed the floor using a deflection criterion of span/1000 instead of the usual span/480 for vibration-controlled floor design. This expensive and over-designed floor ended up having poor sound performance. Here are the floor construction details:

The floor had a span of 11 feet; it was built with 11-7/8" deep wood I-joists spaced at 16" on centres, and ¾" T&G plywood subfloor nailed and glued to the joists. For this type of floor construction, the joist producer recommends a maximum vibration-controlled span of 17 feet and 5 inches. The floor was strapped with 1"x3" wood furs spaced at 16" on centres. It was topped with a 1.5" layer of concrete. Wood sleepers, 2"x2"x2'-3/4", were then screwed through subfloor to the joists. The floor was covered with 3/8" laminated hardwood glued to the concrete topping.

For want of the necessary knowledge and equipment, we did not measure the sound pressure of the floor under footsteps. However, we heard the uncomfortable "drum effect" (as people usually refer the thumping noise) as we walked on the floor.

Case-2:

Wakefield (1999) reported this case at Acoustics Week in Canada 1999. A detailed description of his investigation was published in the conference proceedings (Wakefield 1999). In a new condominium featuring wood floors with concrete toppings, a complaint was received about low frequency thumping noises induced by the footsteps of upstairs neighbours. The noisy floor had a span of 13 feet and 4 inches. It was built with 2x10 lumber joists spaced at 16" on centres and 3/8" plywood sub-floor. It was topped with a 1.5" concrete layer and covered with a carpet. The ceiling consisted of R28 batt insulation in the joists cavities and 5/8" gypsum wallboard suspended from resilient channels.

The field-measured STC and IIC were 56 and 78-80 respectively. These values meet any code requirements. It was noticed, however, that the measured maximum footstep sound pressure of 76 dB in the one-third octave frequency band occurred at 16 Hz, which is much lower than the frequency range of 125 Hz specified in current building codes or the ASTM standard test method for the IIC rating. Wakefield did some retrofit for the problem floor, but with little success. Lin Hu visited the floor after the retrofit and heard the very perceptible thumping noise induced by walking.

The measurements taken on the floor footstep sound in this case confirmed that the frequency range of the noise from heavy impact such as footsteps is much lower than 125 Hz, the frequency range for lightweight impact noise measurement. But there is no well-defined threshold in current building codes to control the low frequency thumping noise induced by footsteps. There is also a lack of understanding of the causes of low frequency thumping noises from a structural point of view. The lack of design guidelines can lead to high occupant dissatisfaction, litigation and costly repair work as demonstrated in the two cases above, assuming that repairs are even possible. Case 2 suggested that repairs might be impossible. Warnock (1993) further pointed out that low frequency thumping impact noises can be more problematic for wood-joist and similar lightweight constructions. However, no effective design solution has been found to the low-frequency thumping noise problem, because the causes of the problem are not fully understood, and no design guidelines exist in current codes and standards. The Nordic countries and Japan have conducted a significant amount of research in this area to establish a threshold, as shown in the work reported by Mortensen (1999), and to establish a test method, as shown in the work reported by Kimura (1980). A more detailed review of their work should be conducted as part of a program on controlling the thumping noises generated by footsteps in wood based floors.

3.3.4 Limited Information on Wood-frame Construction Design for Insulation from Exterior Noise Sources

Japan and European countries have established some requirements for the insulation of buildings from exterior noise (e.g., road and rail traffic, neighbours). For Canadian wood-frame construction to be exported to these countries the noise insulation required for exterior walls, doors and windows needs to be considered. Limited work has been done by CMHC to rate the STC of several wood exterior walls, as well as some access doors and windows of various materials (Ruest 1999, Marshall 1997, and Rousseau 1993).

Noise insulation in wood-frame construction is important in multi-family residential construction and even single-family residential construction for the wood industry to maintain and expand its share of domestic and export housing markets.

In sections 3.3.1-3.3.4, we listed the sound performance issues raised specifically in relation to wood-frame construction. Obviously, no one will resolve these issues for us if we do not address them. Forintek has participated in the IRC sound study since 1992, but no expertise has been established to effectively deal with complaints about unsatisfactory sound performance in wood-frame systems. To satisfy consumers, Forintek needs a technique for in-situ problem solving, field measurement techniques and systems, a computer model to predict the sound performance of wood-frame systems, an understanding of construction solutions for low frequency thumping noises, and retrofit techniques.

By participating in the IRC sound study and from its own floor vibration study, Forintek has built a knowledge base that can be expanded to address the issues raised in connection with wood-frame systems.

4 Proposed Research Plan

A research program consisting of four projects to fully address the issues described above is described in this section. This research program will reinforce the competitiveness of Canadian wood-frame buildings in domestic and export markets.

4.1 Project on Resolving Design Conflicts Between Sound Performance and Other Performance Requirements

This project will develop solutions for resolving conflicts between current construction solutions to improve sound performance in wood-frame construction and other performance requirements.

Conflicting design solutions such as cement-type of topping, floating floor, etc., will be identified. The conflicts will be resolved through computer simulation and laboratory tests. Construction solutions optimising the systems performance of wood-frame construction will be recommended to building codes. A three-year effort may be needed to complete this project.

4.2 Project on Development of Design Information on Field Sound Performance of Wood-frame Construction

This project will develop design information on the field sound performance of wood-frame construction.

The information will be developed by integration of the available data on apparent STC and IIC ratings for various sub-structures of wood-frame construction with the information available on the effects of various flanking paths existing at the joints between sub-structures on the apparent STC and IIC ratings. A method will be developed to account for the effects of flanking paths. Some laboratory tests may be needed to verify the method. A two-year effort may be needed to complete this project.

4.3 Project on Investigation of Thumping Noise in Wood-based Floors: Significance, Mechanism, Cause, and Solutions

This project will investigate thumping noises induced by footsteps in wood-based floors. The investigation will include an evaluation of the significance of the problem, a study of its mechanism and cause, and the development of construction solutions to avoid low frequency thumping noise.

The duration of this study will depend on the priorities assigned to the issues that need to be solved. The complete study should include the following tasks:
1) Standardisation of field measurement methods for the lower frequency sound induced by footsteps;
2) Clarification of mechanism and causes through laboratory study and computer simulations;
3) Establishment of a threshold or design guideline for the lower frequency noise through a consumer survey and field measurements;
4) Development of a retrofit technique for floors producing low frequency thumping noise.

4.4 Project on Wood-frame Construction Insulated from Exterior Noises

This project will develop design information on construction solutions for the insulation of wood-frame construction from exterior noises.

This may be a multi-year project depending on information availability. A review of existing data on STC ratings and design information on exterior wood walls, wood doors and windows will be conducted to identify the gaps in the design information available. Laboratory tests on exterior walls, doors, and windows will be conducted to bridge these gaps. Improved designs for exterior wood walls, wood doors and windows will be developed.

Conducting these projects requires an acoustic measurement system which can be built on the existing Forintek test system for modal analysis. A portable device for in-situ measurement of sound performance is desirable. It may be possible to expand the finite element floor model for the static and vibration performance of wood-based floors developed for our project on modelling continuous two-span floors to include the prediction of sound pressure.

Completion of these projects will eventually establish Forintek's expertise and research facilities to address consumer complaints about poor sound performance in wood-frame buildings. The research facilities and expertise should provide for the development of techniques for in-situ problem solving, field measurement techniques and systems, a computer model to predict the sound performance of wood-frame systems, an understanding of construction solutions for low frequency thumping noises, and retrofit techniques.

5 Co-ordination

Co-ordination with IRC will be an effective way to conduct this research because IRC has a well-equipped acoustic laboratory and the necessary expertise to conduct laboratory measurements of sound performance, which Forintek does not have. Collaboration with IRC and CMHC will facilitate implementation of the final recommendations from this project. The Canadian Wood Council (CWC) will be invited to provide input on research direction, and progress will be monitored by a task group representing the wood industry as well as various industry groups, designers, National Building Code staff, the Canadian Construction Materials Centre (CCMC), the Canadian Home Builders Association (CHBA), and other research groups having expertise in this area .

6 References

National Research Council Canada. 1995. Part 9-Housing and Small Buildings: *National Building Code of Canada.* Ottawa: National Research Council Canada.

National Research Council Canada. 1990. Part 9-Housing and Small Buildings: *National Building Code of Canada.* Ottawa: National Research Council Canada.

Bodlund, K. 1985. Rating of Impact Sound Insulation between Dwellings. *Journal of Sound and Vibration,* 102(3): p381.

Warnock, A.C.C. (1993). Sound Transmission Through Floors: Phase III – Summary Report. Client Report for Canada Mortgage and Housing Corporation. No.A-1018.1. CMHC. Ottawa: Housing Innovation Division.

Richardson, L. R. and Batista, M. 2001. Fire-resistance and Sound Transmission-Class Ratings for Generic Wood-frame Assemblies. Canadian Forest Service Report No. 02. Forintek Canada Corp. Ottawa.

Nightingale, T.R.T. and Halliwell, R.E. (1997). Flanking transmission at joints in multi-family dwellings-Phase 1: Transmission via fire stops. Final Report to project consortium. No. A-1042.F. IRC. Ottawa: Acoustic Laboratory.

Hu, L. J. 2001. Assessment of Wood-Based Floor Buildability Issues. Final Report No. 48 for Canadian Forest Service. Forintek Canada Corp. Sainte-Foy.

Richardson, L. 2000. Flanking Sound Transmission in Multi-family Dwellings-Phase II Transmission via Structural Connections. Meeting Report of the Fourth Meeting. Forintek Canada Corp. Ottawa: Fire Research Group.

Talja, A. and Toratti, T. 2000. Effect of floating floors on the vibration performance of wood-concrete composite floors. *Proceedings of World Conference on Timber Engineering 2000*; July 31- August 3, 2000; Whistler: 8.2.3.

Ungar, E. E. Beraner L. L. and Ver I. L., editors. 1992. Structural Damping: *Noise and Vibration Control Engineering.* Toronto: John Wiley & Sons, Inc. 451-481.

Wakefield, C. W. 1999. Control of Low-Frequency Footstep Sound & Vibration Transmission Though a Wood-frame, Concrete-Topped Floor. *Journal of the Canadian Acoustics Association.* 27(3):p116.

Mortensen, F.R. 1999. Subjective Evaluation of Noise from Neighbours with Focus on Low Frequencies. Main Project Report No.53. Technical University of Denmark. Lyngby: Department of Acoustic Technology.

Kimura, S. 1980. Method for Field Measurement of Floor Impact Sound Level Using Heavy Impact Source. *Proceedings of 10th I.C.A.* Sydney: ISO/TC 43/SC 2/WG 18 N 53.

Ruest, K. 1999. Insulation Provided by Exterior Walls in Wood Construction. Project Report of Canada Mortgage and Housing Corporation. CMHC. Ottawa.

Marshall, S. 1997. Noise Isolation Provided by Windows in Residential Projects. Project Report of Mortgage and Housing Corporation. CMHC. Ottawa.

Rousseau, J. 1993. Research Project on the Noise Isolation Provided by Access Doors in Multi-Dwelling Buildings. Project Report of Mortgage and Housing Corporation. CMHC. Ottawa.