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Mid-rise wood constructions: specifications of mid-rise envelopes for hygrothermal assessment: report to Research Consortium for Wood and Wood-Hybrid Mid-Rise Buildings

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REPORT TO RESEARCH CONSORTIUM FOR WOOD AND WOOD-HYBRID MID-RISE BUILDINGS

MID-RISE WOOD CONSTRUCTIONS – Specifications of Mid-rise Envelopes for Hygrothermal Assessment

CLIENT REPORT: A1-100035-03.1

December 31, 2014

National Research Council Canada Conseil national de recherches Canada

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REPORT TO RESEARCH CONSORTIUM FOR WOOD AND WOOD-HYBRID MID-RISE BUILDINGS

Mid-Rise Wood Constructions – Specifications of Mid-Rise Envelopes for Hygrothermal Assessment

K. Abdulghani, S.M. Cornick, B. Di Lenardo, G. Ganapathy, M.A. Lacasse, W. Maref, T.V. Moore, P. Mukhopadhyaya, M. Nicholls, H.H. Saber, M.C. Swinton

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Prepared for	Canadian Wood Council FPInnovations Régie du bâtiment du Québec HER MAJESTY THE QUEEN IN RIGHT OF ONTARIO as represented by the Minister of Municipal Affairs and Housing

18 pages

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The research consortium has been supported by Natural Resources Canada and the Ontario and Quebec building authorities, with research being conducted by the National Research Council (NRC), Canadian Wood Council (CWC) and FPInnovations (FPI). Two working groups were established, with participants from NRC, CWC, FPI and Municipal Affairs and Housing (Ontario) – one on fire and building envelope and the other on structure and acoustics. Working group meetings have been held on a biweekly basis to develop and design test methods, design test assemblies and select materials for the test arrangements. The results of tests are discussed on an ongoing basis.

The following staff members of project partner/collaborator organizations have contributed to the working groups and this progress report:

CWC: Rodney McPhee, Ineke Van Zeeland, Peggy Lepper;

FPI: Richard Desjardins, Mohammad Mohammad, Christian Dagenais, Chun Ni, Lin Hu, Lindsay Osborne, Ling Lu, Ciprian Pirvu; Julie Frapper (Nordic);

MAH: Nancy Smith;

NRC: Khaled Abdulghani, Steve Cornick, Bruno Di Lenardo, Gnanamurugan Ganapathy, Michael Lacasse, Wahid Maref, Travis Moore, Phalguni Mukhopadhyaya, Mike Nicholls, Hamed Saber, Mike Swinton

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MID-RISE WOOD CONSTRUCTIONS – SPECIFICATIONS OF MID-RISE ENVELOPES FOR HYGROTHERMAL ASSESSMENT

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1. INTRODUCTION

The role of the Building Envelope team in this project is to assess whether alternate wood-based building envelope solutions developed by the Fire Team to meet the fire provisions of NBC 2010, also meet NBC Part 5 requirements relating to the protection of the building envelope from long term degradation due to uncontrolled heat, air, moisture and precipitation (HAMP) ingress into the building envelope of mid-rise buildings.

Initially, the Fire Team identified three types of exterior wall assemblies that would form part of their investigation:

a) Noncombustible exterior wall systems (the ‘fire benchmark’).
b) ‘Protected’ envelope assemblies featuring combustible structural elements (light frame wood approaches (LWF) and heavy timber (Cross-Laminated Timber - (CLT)) using noncombustible finishes and sheathing such as gypsum board.
c) ‘Protected’ envelope assemblies featuring combustible structural elements (LWF and heavy timber) using fire-retardant treated panels such as exterior sheathing.

Approaches b & c are to be evaluated for their performance relating to their ability to control heat, air, moisture, and precipitation for a range of climate conditions across Canada. This is undertaken to ensure that recommendations developed in this study to address fire performance requirements of the NBC are also compatible with envelope HAMP performance requirements of Part 5 of the NBC.

To perform the hygrothermal assessments of the proposed alternate solutions for combustible building envelopes, the following tasks were specified in the plan of work for the project:

- Task 1 – Specifications of Envelope Details
- Task 2 – Selection of Climate Location & Climate Loads
- Task 3 – Water Penetration Lab Experiments
- Task 4 – Development of Hygrothermal Properties
- Task 5 – Benchmarking Experiments for Hygrothermal Modelling
- Task 6 – Hygrothermal Modelling and Analysis
- Task 7 – Development of an Opinion on ‘deemed to comply’

This report is for Task 1 only.

2. SPECIFICATIONS OF ENVELOPE DETAILS

In a process of consultations with stakeholders, including the Canadian Wood Council (CWC), FPInnovations, and consultations with NRC's Fire and Acoustics teams, specifications were developed for 2.44 m x 2.44 m wall specimens that would be investigated for hygrothermal performance.

2.1 Main Elements of the LWF Envelope

The key elements of the mid-rise wood frame envelope are similar in many respects to conventional low-rise envelopes since the exterior walls planned for mid-rise buildings are not typically load-bearing for the main structure. Nevertheless, there may be an intensification of studs in mid-rise walls due to the prevalence of large window areas in examples of buildings built to date. As a result, what is left of the actual opaque wall features a greater proportion of studs per unit area. As well, the envelope walls investigated by the fire team in this project featured perhaps less conventional selections of materials and numbers of layers involved to achieve both the maximization of fire load within the envelope to anticipate worse case fire load conditions on the one hand, and on the other hand, the fire team included elements that provide additional protection of the envelope from the fire safety standpoint, as part of the 'encapsulation strategy' investigated by the Fire team for LWF mid-rise construction.

The elements to be specified are:

- Interior finish, including finishing boards and paint
- Air and vapour barrier control membranes, if any
- Wood Framing
- Insulation in the stud cavities
- Sheathing Membranes or Weather Resistant Barriers (WRBs)
- Cladding system, including rainscreen cavity as applicable, and the cladding itself.

The selections for each of these elements will be presented in the next several sections along with the rationale and options that result from discussions with Fire and Acoustics teams.

2.2 Meeting Minimum Code with Generic Products

Most readers will be more familiar with proprietary manufactured products. For example several building product suppliers have their own brand of exterior grade gypsum sheathing commonly used in commercial building construction, which features a water and mould-resistant gypsum core encased in a glass-mat facer on both sides. Georgia Pacific DensGlass Gold and Securock are examples of such proprietary products. However, since this research is in support of generating information for potential code changes, it was important that the materials selected for the investigation were as generic as possible so as not to preclude the full range of commercial products available in the market place, and also ensure that the selection of materials was likewise representative of a code minimum solution in terms of performance. For example, the sheathing specified in this project is simply exterior grade gypsum – a product that is still available but is said to be seldom used. As a result, whatever additional fire resistance properties and moisture resistance properties that are claimed by the manufacturers of proprietary products, such enhanced properties are currently not needed to make the case for the proposed 'encapsulation strategy' for fire resistance, nor for the resulting moisture performance.

A similar rationale applies to the selection of type X gypsum that forms part of the 'encapsulation strategy' for fire performance, and for the selection of a generic fibre-cement panel for the cladding system.

2.3 Selections for each Element of the LWF Envelope

Canadian wood frame wall construction has a long history of managing moisture loads with proper design and construction detailing, while meeting minimum NBC requirements. Wall specifications for mid-rise wood design may differ from traditional construction of LWF as provided in NBC Part 9 due to added materials or non-traditional combinations of materials used to meet structural, fire and acoustical requirements of mid-rise buildings. As such, hygrothermal analysis is recommended to be performed as a check on assemblies investigated in this study, particularly as specified by the Fire Team. The following sections document some non-traditional features investigated by the Fire Team (principally) and the Acoustic Team for mid-rise LWF construction, which may impact on the moisture management capability of the wall system. These specifications will be used by the Hygrothermal Assessment Team to construct models representing the walls to be investigated.

Note that the main elements of the Mid-rise Light Wood Frame Wall specifications detailed in the following sections are illustrated in Figure 1, in Section 3.1.

2.3.1 Interior Finishing Materials

Information related to the specifications for the interior finish is provided in Table 1. Information in this, and all subsequent Tables, includes specifications for conventional LWF construction in low-rise buildings as well as that of the mid-rise version. A rationale is provided for the change in specifications and considerations in respect to hygrothermal modelling are also provided.

With respect to specifications for interior finishing materials, these materials are involved in the Fire Team's strategy for 'encapsulation'. As a result, instead of a single layer of regular gypsum board, 2 layers of Type X gypsum board are specified.

Table 1. Interior Finish Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Interior Finish	Latex paint, latex primer 12.7 mm conventional interior grade gypsum board.	Latex paint, latex primer **Two** layers of 12.7 mm gypsum board Type X, complying with CAN/CSA-A82-27-M91, ASTM C79 and ASTM C1396 **Optional:** 2 layers of 12.7 mm fibre-cement board	2 layers of gypsum is part of the 'encapsulation strategy' being investigated by Fire.	Generic hygrothermal properties of gypsum board will be used in the simulation. More specific property characterization may be required if the 2 layers of gypsum are found to significantly affect the result.
		Optional: Include resilient channels, resulting in air space.	For possible acoustics performance, to reduce flanking up and down the exterior walls to suites above and below.	Additional interior air space due to resilient channel is not believed to have a significant effect on hygrothermal performance.

2.3.2 Air Barrier System and Vapour Barrier Materials

Information related to specifications for the air barrier system and vapour barrier materials is provided in Table 2. A common practice to meet the NBC vapour barrier requirements and air barrier system requirements for wood-frame walls would be to install a 6 mil polyethylene membrane sandwiched between the interior gypsum finish and the studs/insulation. To complete the air barrier system, specifications would include detailing of the air barrier at joints, penetrations and windows, whilst assuring continuity of the air barrier system across the floor plate. For the purposes of this moisture management assessment, and because spray polyurethane foam (SPF) is specified as the insulation (see section 2.3.4), both the foam and the studs in combination can deliver vapour diffusion control and air leakage control through the face of the wall. Similar provisions on air barrier detailing across penetrations and the floor plate are also required for the SPF approach. As such, and since the intent is to analyze the moisture performance through the face of the wall, the hygrothermal simulations, in this case, will not include an additional air barrier system or vapour barrier. As an option, variations with 0.15 mm polyethylene can be investigated where SPF is not used.

Table 2. Air Barrier System and Vapour Barrier Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Air Barrier System and Vapour Barrier	0.15 mm polyethylene (vapour barrier and also a key part of the air barrier system). Continuous or lapped and returned into rough openings at windows, with acoustical sealant	No additional membrane (no poly). **Optional approaches could include:** 0.15 mm polyethylene (vapour barrier and also a key part of the air barrier system), applied continuously, and returned into rough openings at windows, with acoustical sealant. Rigid air barrier systems such as by using interior drywall or exterior structural sheathing, or using exterior sheathing membrane as the air barrier may provide better performance for a mid-rise wood building.	If poly is used: A/V barrier material complying with NBC 5.4 & NBC 5.5. Complying with CAN/ULC-S741.	For modeling only, no additional vapour barrier membrane will be used in test specimen. System air leakage characteristic will be modeled at 0.2 L/s m^2 Pa (Part 5 Appendix). Material airtightness ≤ 0.02 L/s m^2 @ 75 Pascal - (NBC 5.4.1.2.(1).a). Poly must be supported to withstand wind loads, if flexible batts are used in the cavity.

2.3.3 Framing

Information related to specifications for the framing is provided in Table 3. The Fire Team's research featured a number of configurations for tests to characterise fire performance of mid-rise LWF systems, two of which have been selected for hygrothermal assessment. The first LWF system does not represent a departure from conventional low-rise framing: 38 x 140 mm @ 406 mm (2x6" @ 16" o.c.). Nevertheless, the fire test featured a full cavity of spray polyurethane foam. The degree to which the foam represents a potential encapsulation of moisture in the studs is to be addressed in the hygrothermal investigation.

The second LWF system configuration (38 x 140 mm @ 150 mm o.c. / 2" x 6 " staggered studs spaced at 6 " o.c.) was used in the construction of an exterior wall for the apartment fire test. In this configuration, conventional batts were used as the insulation. With a stud being placed at every 150 mm, this represents, on average, an intensification of the stud content of the wall and the capacity of the studs in this wall to dry-out when subjected to rain events will be assessed under various climatic conditions.

Note on Selection of Baseline Framing for Hygrothermal Analysis:

The Fire Team's reference used a light-frame metal stud system for non-combustible envelopes. Since metal studs do not absorb water they exhibit different deterioration mechanisms than wood under high moisture conditions. Therefore the Fire Team's selection of a baseline wall system is not a useful baseline for hygrothermal comparisons. An alternate baseline will be proposed as part of Task 7.

Table 3. Framing Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Framing	38 x 140 mm @ 406 mm (2x6" @ 16" o.c.) *Fire Team's Reference: Light Frame Non-combustible Envelope with staggered studs @ 305 mm o.c.and 200 mm batts* *(See note below table)*	38 x 140 mm @ 406 mm (2x6" @ 16" o.c.) **Optional**: (Used for the Apartment fire): 38 x 140 mm @ 150 mm o.c. (2"x6" staggered studs spaced at 6" o.c.) on opposite sides of the framing (i.e. 12" o.c. on same side). Top and bottom plates are 38 x 184 mm (2"x8" plates) Fire & Acoustics may investigate build-up columns (3 x 38 x 140 mm studs, staggered on a 38 x 184 mm plate) at 400 mm o.c.	Selections specified by Fire for their performance comparisons. The Fire Team's reference non-combustible construction is a Light Weight Non-combustible exterior wall specified by qualified engineers to meet NBC requirements.	The 1st option for LWF framing is conventional construction, nevertheless with cavities filled with spray polyurethane foam, the moisture management capability of this wall will be assessed. The Apartment fire configuration represents an intensification of wood studs per unit area. Batts will be used as the insulation. Dry-out capability of the studs will be assessed.

2.3.4 Insulation Specifications

Information related to specifications for insulation is provided in Table 4. As discussed in the previous section, the types of insulation and thicknesses were specified by the Fire Team. Products meeting the standards cited in the following table will be specified for modelling.

Different insulations and wall configurations may be required to meet NECB 2011 with a 38 x 140 mm cavity. Meeting the requirements in colder regions of the country, such as Zone 7A, may require the cavity to be filled with SPF or batt insulations with higher thermal resistivity combined with additional insulation outboard of the cavity. Minimum thermal requirements for envelopes by climatic zone are provided in Appendix A and Examples of NECB 2011 Thermal Requirements for walls by location are given in Appendix B. Example calculations of effective thermal resistance of the wall assembly are shown in Appendix C, along with the zones that can be met with the specified insulation and wall configuration.

Table 4. Insulation Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Insulation	Batts installed in stud space cavities complying with CAN/ULC S702-09	Spray Foam installed to fill stud cavities complying CAN/ULC S705.1-01 for SPF (ULC S705.2 installation standard) Optional: Mineral or Glass Fibre batts complying with CAN/ULC S702-09. Exterior rigid foam insulation is another alternative that could be investigated.	Insulation thickness selected to contribute to maximum overall effective thermal transmittance to meet the requirements of Table 3.2.2.2, Division B, Part 3 – Building Envelope, National Energy Code of Buildings 2011	The use of less vapour permeable foam insulations may trap excess construction moisture in studs for longer periods of time – to be investigated.

2.3.5 Sheathing Specifications

Table 7. Sheathing Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Sheathing	Exterior grade gypsum sheathing.	12.7 mm Exterior Grade Gypsum Board – old style gypsum board with gypsum paper on both sides – difficult to find) Selected by the Fire Team to meet code minimum with a generic product. Alternately, 15.9 mm flame-retardant treated (FRT) OSB or plywood	For the Fire tests, conventional gypsum with paper on both sides is deemed to be Fire's 'worse case' due to flame spread issues in the air space behind the cladding For the moisture performance assessment, the envelope team should use plywood or FRT plywood, as may be used by industry for mid-rise buildings currently built or under construction. Thickness chosen to satisfy structural requirements and encapsulation strategy for Fire. Expansion/contraction gaps between plywood sheets may need blocking for structural reasons. Plywood behind the weather resistant barrier (building paper or other) does not need to be treated for resistance to biological deterioration – source: Paul Morris, FPInnovations. However, the plywood will be FRT grade as per NRC Fire Team specifications. Light frame non-combustible stud baseline wall may need additional semi-rigid mineral fibre insulation to meet assembly effective thermal transmittance in NECB - see Appendix A.	For modelling purposes, hygrothermal properties need to be measured for FRT plywood. Specimens to be provided by Fire Team. Note: commercial available products are actually 'interior grade'. But since these are protected by cladding and WRB, they should be acceptable for use in the hygrothermal analysis. (Note: the generic description for commonly used exterior grade gypsum is: water and mould-resistant gypsum core encased in a glass-mat facer on both sides)

2.3.6 Sheathing Membrane Specifications

Table 8. Sheathing Membrane Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Sheathing Membrane	2 layers asphalt-impregnated building paper complying with CAN/CGSB-51.32-M77, as determined by ASTM D779	2 layers asphalt-impregnated building paper complying with CAN/CGSB-51.32-M77, as determined by ASTM D779	Intended to meet NBC 5.6.1.1 & NBC 5.6.2.2.(3) are general requirement to minimize ingress to precipitation into the assembly. (Deemed to comply solutions from NBC Part 9 – may need engineering review). Other sheathing membrane products may be more commonly used.	CCMC indicates that when the sheathing is structural, 2 layers of building paper are required, as per NBC. Note: Properties of sheathing paper relating to water vapour permeance need to be double-checked by Envelope HAMP properties and modelling teams, since NBC 2010 Table A-9.25.5.1.(1) is being amended.

2.3.7 Cladding Assembly Specifications

Table 9. Cladding Assembly Specifications

	Conventional LWF in low-rise buildings	Mid-rise LWF in this study	Rationale for difference: Fire or Acoustics	Hygrothermal Modelling Considerations
Cladding Fastening System	25 mm air space & brick ties	13 x 50 mm pressure treated plywood strapping, 400 mm o.c., installed vertically with flashing at each floor	Strips of preservative pressure treated plywood (not FRT) recommended as furring by FPInnovations. Intended to meet NBC 5.6.1.1& NBC 5.6.2.2.(3); which are general requirement to minimize ingress of precipitation into the assembly. (Deemed to comply solutions from NBC Part 9 – may need engineering review)	Role of 13 mm air space formed by the strapping will be modelled for moisture performance and energy
Cladding	Brick veneer	Fibre-cement panels	Fibre-cement panels recommended as an alternative by FPInnovations. Generic fibre-cement panels to be used, not proprietary panels with specific fire ratings.	Discussions between Fire Team and CWC & FPInnovations have indicated that some fibre cement panel products can be deemed to be non-combustible. (Wood fibre content will affect fire properties.)

2.4 Summary of Interrelated Factors from Fire and Acoustics Teams

As highlighted in the preceding tables, a number of factors were flagged by the Fire Team and Acoustics Teams for consideration that relate to moisture control and vice versa. These are summarised in Table 10.

Table 10. Summary of Issues Interrelated to Moisture Management considering issues of Moisture, Energy, Fire and Acoustics

Envelope component	Interrelated Issues with Fire	Hygrothermal Issues
Cavity insulation	Need to explore 'Encapsulation strategy' in combination with combustible insulation in cavity	High R-value, combustible insulation products could be used to meet NECB 2011 in some locations. Will such products limit the ability of mid-rise wood studs to dry?
Sheathing materials	Fire-retardant treated wood-based sheathing materials being investigated as potential 'Encapsulation material'	Does the fire treatment of plywood and OSB alter the hygrothermal properties of the sheathing? If so, does this create a moisture performance issue for the envelope?
Cladding system	Minimum code, non-combustible cladding system: fibre-cement panels mounted on treated plywood strips. The fire Team investigated the role of the air space on exterior wall propagation of fire. Airspace is flashed at each floor	Does the cladding system selected by the Fire Team impact moisture management? The cladding system's resistance to water entry as a function of weather parameters was established in water entry tests undertaken in Task 4. Flashing at each floor defines the height of rainscreen airspace for modelling
Sheathing paper	Two layers of code compliant sheathing paper may add to the fire load and postulated flame spread inside the rainscreen cavity - investigated by Fire Team.	Two layers of code compliant sheathing paper recommended for claddings that absorb water and moisture. Do the additional materials delay the outward drying in some climates? To be assessed in modelling
Envelope component	**Interrelated Issues with Acoustics**	**Hygrothermal Issues**
Interior finishing assembly	Are resilient channels needed behind interior finishes to reduce flanking through the envelope to adjacent suites?	Does the additional interior air space in the envelope assembly, formed by the resilient channels, affect the hygrothermal performance of the envelope? Current answer: unlikely. Parametric investigation is optional.

3 RECOMMENDATIONS FOR HYGROTHERMAL ASSESSMENT OF LWF AND CLT WALL

3.1 Recommended Specification of the LWF Wall

The following exterior wall configuration will be the subject of the hygrothermal modelling assessment. Of the 3 options shown, the sheathing material featuring the least permeable properties will be selected for hygrothermal assessment in the different geographic locations.

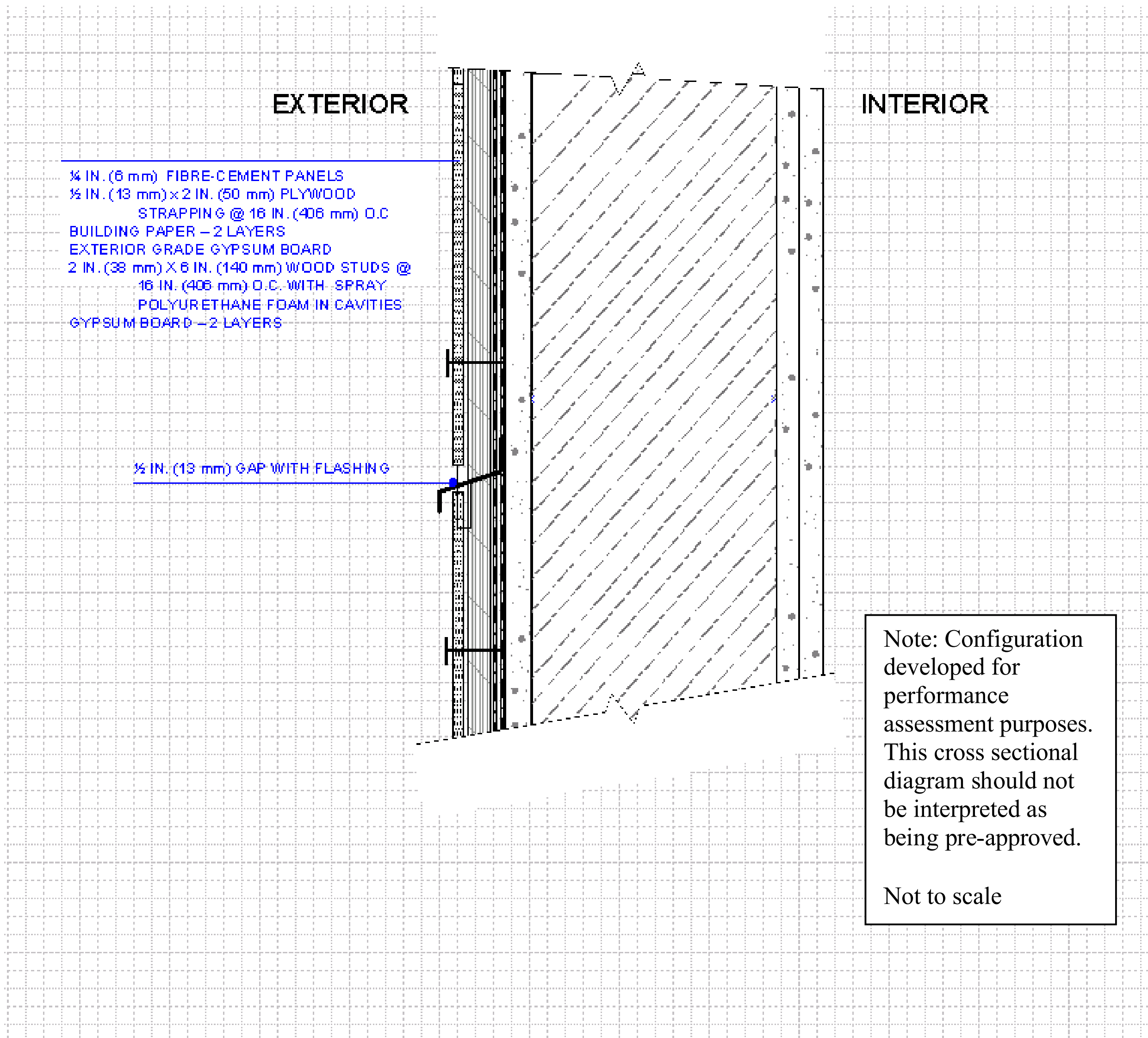

Figure 1. Cross Sectional Diagram of the Mid-rise Light Wood Frame Assembly to be Assessed for Heat and Moisture Performance (*not to scale*)

3.2 Specification of the Cross-Laminated Timber Wall

Both the Fire Team and Acoustics Team have performed tests on Cross-Laminated Timber (CLT) load-bearing party walls and shear wall assemblies. CLT construction can also be used for the exterior envelope, and accordingly, a CLT envelope specification was developed. Our recommendation is based on a configuration proposed by FPInnovations[1] combined with the encapsulation strategy specified above to meet the recommendations of the Fire Team for LWF, with the same rationale. A 3-ply CLT was chosen that was consistent with one concept design by FPInnovations[1]. Also note that the CLT thicknesses used in buildings are mostly governed by structural requirements as well as available products, panel lay-up, and other factors. Mid-rise buildings typically need thicker CLT panels. The insulated assembly consists of 2x6" (38 x 140 mm) stud framing with 140 mm mineral fibre insulation. The resulting cross sectional diagram is shown in Figure 2.

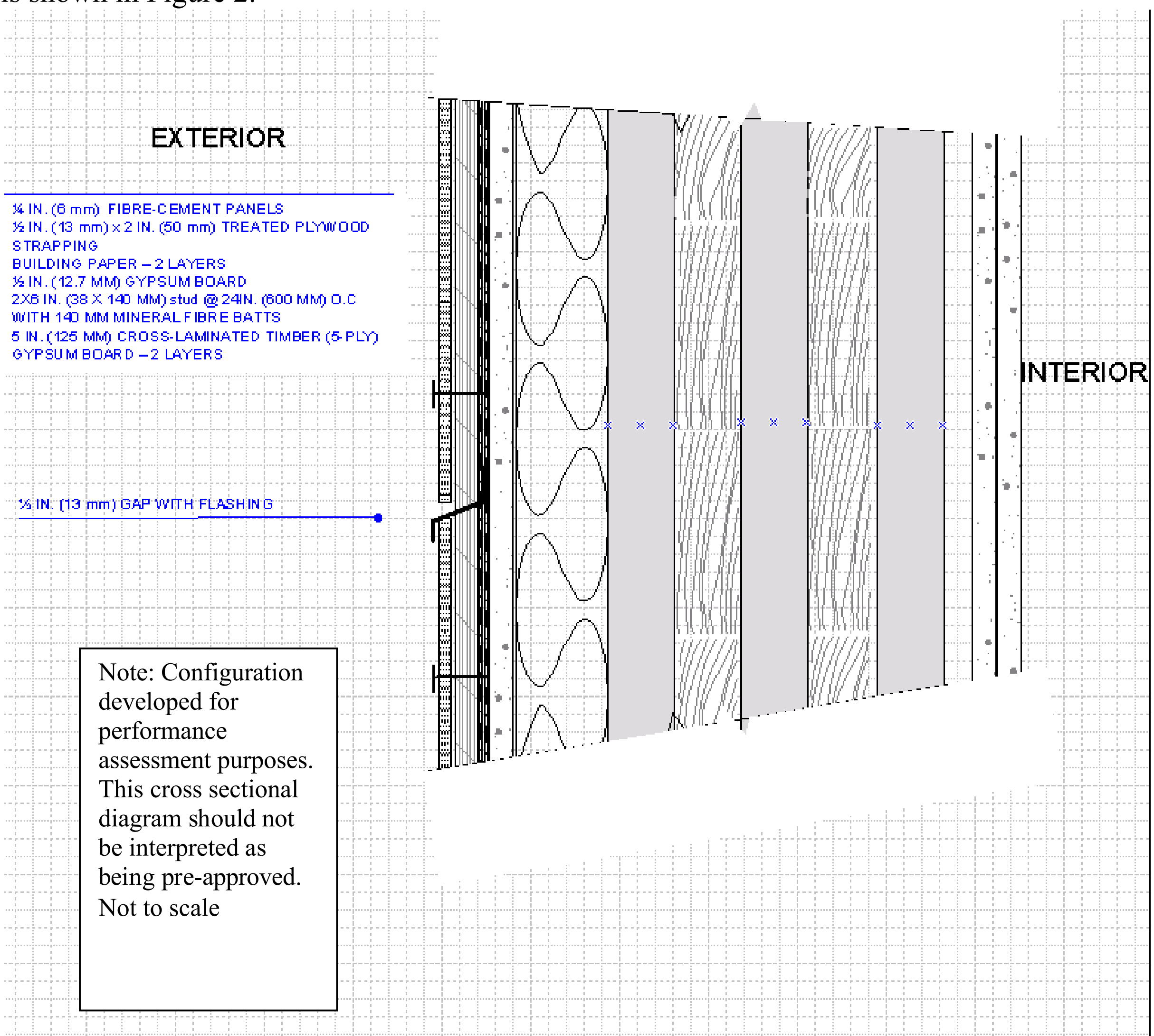

Figure 2. Cross Sectional Diagram of the Cross-Laminated Timber Assembly to be Assessed for Heat and Moisture Performance (*not to scale*)

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[1] CLT Handbook: Cross-Laminated Timber; edited by Sylvain Gagnon and Ciprian Pirvu. (c) FPInnovations, 2011. Chapter 10 Enclosure, Figure 6.

(Note: to accommodate electrical wiring and to achieve superior flanking sound control, the two layers of interior finishes should be mounted on resilient channels.)

This specification differs from the FPInnovations Concept due to the encapsulation strategy developed by the Fire Team. In the FPInnovations Concept, the Weather Resistant Barrier (WRB – in their case building paper) was installed directly outboard of the CLT, since the space formed between the mineral fibre insulation and the cladding system was their designated rainscreen. As such, the drainable insulation could get wet with incidental water entry into the rainscreen assembly and thus the CLT requires protection with a direct-applied WRB. On the other hand, the 'encapsulation strategy' developed by the Fire Team requires that the exterior gypsum sheathing be placed outboard of the 2x6" (38 x 140 mm) studs to encapsulate the studs as well as the CLT. This moves the rainscreen design outboard of the gypsum, so the 2 layers of the WRB are needed to protect the gypsum. To complete the assembly, the rainscreen cavity is formed with the same treated plywood strapping specified for the LWF and with the same fibre-cement panels cladding on the outside.

The Fire Team noted that this proposed design moves the WRB outside the encapsulation layer of the gypsum which may not be ideal from a fire resistance standpoint, but the configuration was nevertheless shown to perform well with the fibre-cement panel used as cladding in one of the envelope tests by the Fire Team. So this design concept requires a compromise between fire and moisture performance. This will be discussed with stakeholders before proceeding with the hygrothermal analysis.

Once this CLT assembly is approved for further investigation, it will be simulated for hygrothermal performance using the hygrothermal properties of the CLT that were previously developed for FPInnovations.

Appendix A - Minimum Thermal Requirements for Envelopes by Climatic Zone – Walls - 2011 National Energy Code for Buildings

A. Overall Thermal Transmittance

Above-ground Opaque Building Assembly	Heating Degree-Days of Building Location in Celsius Degree-Days					
	Zone 4: < 3000	Zone 5: 3000 to 3999	Zone 6: 4000 to 4999	Zone 7A: 5000 to 5999	Zone 7B: 6000 to 6999	Zone 8: ≥ 7000
	Maximum Overall Thermal Transmittance, in $W/(m^2 \cdot K)$					
Walls	0.315	0.278	0.247	0.210	0.210	0.183

B. Conversion to Overall Thermal Resistance (RSI)

Above-ground Opaque Building Assembly	Heating Degree-Days of Building Location in Celsius Degree-Days					
	Zone 4: < 3000	Zone 5: 3000 to 3999	Zone 6: 4000 to 4999	Zone 7A: 5000 to 5999	Zone 7B: 6000 to 6999	Zone 8: ≥ 7000
	Minimum Overall Thermal Resistance, in $(m^2 \cdot K)/W$					
Walls	3.17	3.60	4.05	4.76	4.76	5.46

C. Conversion to Overall Thermal Resistance (Imperial units)

Above-ground Opaque Building Assembly	Heating Degree-Days of Building Location in Celsius Degree-Days					
	Zone 4: < 3000	Zone 5: 3000 to 3999	Zone 6: 4000 to 4999	Zone 7A: 5000 to 5999	Zone 7B: 6000 to 6999	Zone 8: ≥ 7000
	Minimum Overall Thermal Resistance, in $(h.ft^2 \cdot F)/BTU$					
Walls	18.0	20.4	23.0	27.0	27.0	31.0

Appendix B - Examples of NECB 2011 Thermal Requirements for Walls By Location

City	Degree Days (°C-days) (NBC 2010)	2011 National Energy Code For Buildings Zones	Maximum Effective Thermal Transmittance ($W/m^2 \cdot K$)	Minimum Effective Thermal Resistance ($m^2 \cdot K/W$)
Halifax	4000	Zone 6	0.247	4.05
Vancouver	2825	Zone 4	0.315	3.17
St-John's, NL	4800	Zone 6	0.247	4.05
Quebec City	5080	Zone 7A	0.210	4.76
Victoria	2650	Zone 4	0.315	3.17
Chatham/Miramichi, NB	4950	Zone 6	0.247	4.05
Montreal	4200	Zone 6	0.247	4.05
Iqaluit	9980	Zone 8	0.183	5.46
Toronto	3520	Zone 5	0.278	3.60
Windsor, ON	3400	Zone 5	0.278	3.60
Ottawa	4440	Zone 6	0.247	4.05
Yellowknife	8170	Zone 8	0.183	5.46
Winnipeg	5670	Zone 7A	0.210	4.76
Whitehorse	6580	Zone 7B	0.210	4.76
Edmonton	5120	Zone 7A	0.210	4.76
Saskatoon	5700	Zone 7A	0.210	4.76
Regina	5600	Zone 7A	0.210	4.76
Calgary	5000	Zone 7A	0.210	4.76

Appendix C – Example Calculations of Effective Thermal Resistance of Specified Walls

Example 1. Mid-Rise Wood Wall - Effective R-value with SPF in Wood Stud cavities 300 mm o.c.; 2 Gypsum layers

Component	thickness	RSI/mm	RSI_F through stud	RSI_I through insulation
	mm		m2.°C/W	m2.°C/W
Outside air film			0.03	0.03
Fibre-Cement Lap Siding			0.11	0.11
Sheathing paper x 2			0.02	0.02
Exterior Insulation				
Plywood	13	0.011	0.143	0.143
Stud	140	0.011	1.55	-
Insulation SPF Medium D	130	0.051	-	6.67
Air Space	10			0.18
Polyethylene (vapour barrier)			-	-
Gypsum x2 @ 12.7 mm	25.4	0.0061	0.15	0.15
Interior film			0.12	0.12
		Total	2.13	7.43
	300 mm o.c.	Percent of total area	22.5%	77.5%
		RSI_T	**4.76**	Meets NECB Zone 7A
R =	27.0	Overall thermal transmittance	0.210	

		RSI_{T2}	**3.83**	
		RSI_{T3}	**4.59**	(Isothermal Planes Calc)
R =	26.4	**RSI_T**	**4.66**	(2/5 & 3/5 blend of 2 paths)

Example 2. Mid-Rise Wood Wall - Effective R-value with High Density MF in Wood Stud cavities 300 mm o.c.				
Component	**thickness**	**RSI/mm**	**RSI_F through stud**	**RSI_I through insulation**
	mm		m2.°C/W	m2.°C/W
Outside air film			0.03	0.03
Fibre-Cement Lap Siding			0.11	0.11
Sheathing paper x 2			0.02	0.02
Plywood	13	0.011	0.143	0.143
Stud	140	0.011	1.55	-
MF - High Density Product	140	0.031	-	4.39
Air Space	--			0.18
Polyethylene (vapour barrier)			-	-
Gypsum x 2 @ 12.7 mm	25.4	0.0061	0.15	0.15
Interior film			0.12	0.12
		Total	2.13	5.15
	300 mm o.c.	Percent of total area	22.5%	77.5%
		RSI_T	**3.90**	Meets NECB Zone 5
R =	22.2	Overall thermal transmittance	0.256	

		RSI_{T2}	**3.11**	
		RSI_{T3}	**3.87**	(Isothermal Planes Calc)
R =	22.0	**RSI_T**	**3.88**	(2/5 & 3/5 blend of 2 paths)

Example 3. Effective R-value of 3 Ply CLT assembly with MF in 140 mm Wood Stud cavities 600 mm o.c.				
Component	**thickness**	**RSI/mm**	**RSI_F through stud**	**RSI_I through insulation**
	mm		m^2.°C/W	m^2.°C/W
Outside air film			0.03	0.03
Fibre-Cement Lap Siding			0.11	0.11
Air space			0.18	0.18
Sheathing paper x 2			0.02	0.02
Gypsum Sheathing	12.7	0.0061	0.08	0.08
Stud	140	0.011	1.56	-
Mineral Fibre Batt Insulation	140	0.026	-	3.64
3 Ply Cross-Laminated Timber	76.2	0.011	0.85	0.85
Gypsum x 2 @ 12.7 mm	25.4	0.0061	0.15	0.15
Interior film			0.12	0.12
		Total	3.09	5.18
	600 mm o.c.	Percent of total area	15.9%	84.1%
		RSI_T	**4.68**	Meets up to Zone 6
R =	26.6	Overall thermal transmittance	0.214	

		RSI_{T2}	**3.00**	
		RSI_{T3}	**4.54**	(Isothermal Planes Calc)
R =	26.1	**RSI_T**	**4.60**	(2/5 & 3/5 blend of 2 paths)