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Use of Computer Fire Modelling to Support Alternative Solutions – Wood In-fill Wall and Cladding Materials

BC Advisory Group on Advanced Wood Design Solutions

Edited by: Conroy Lum

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STATUS see Appendix I for background

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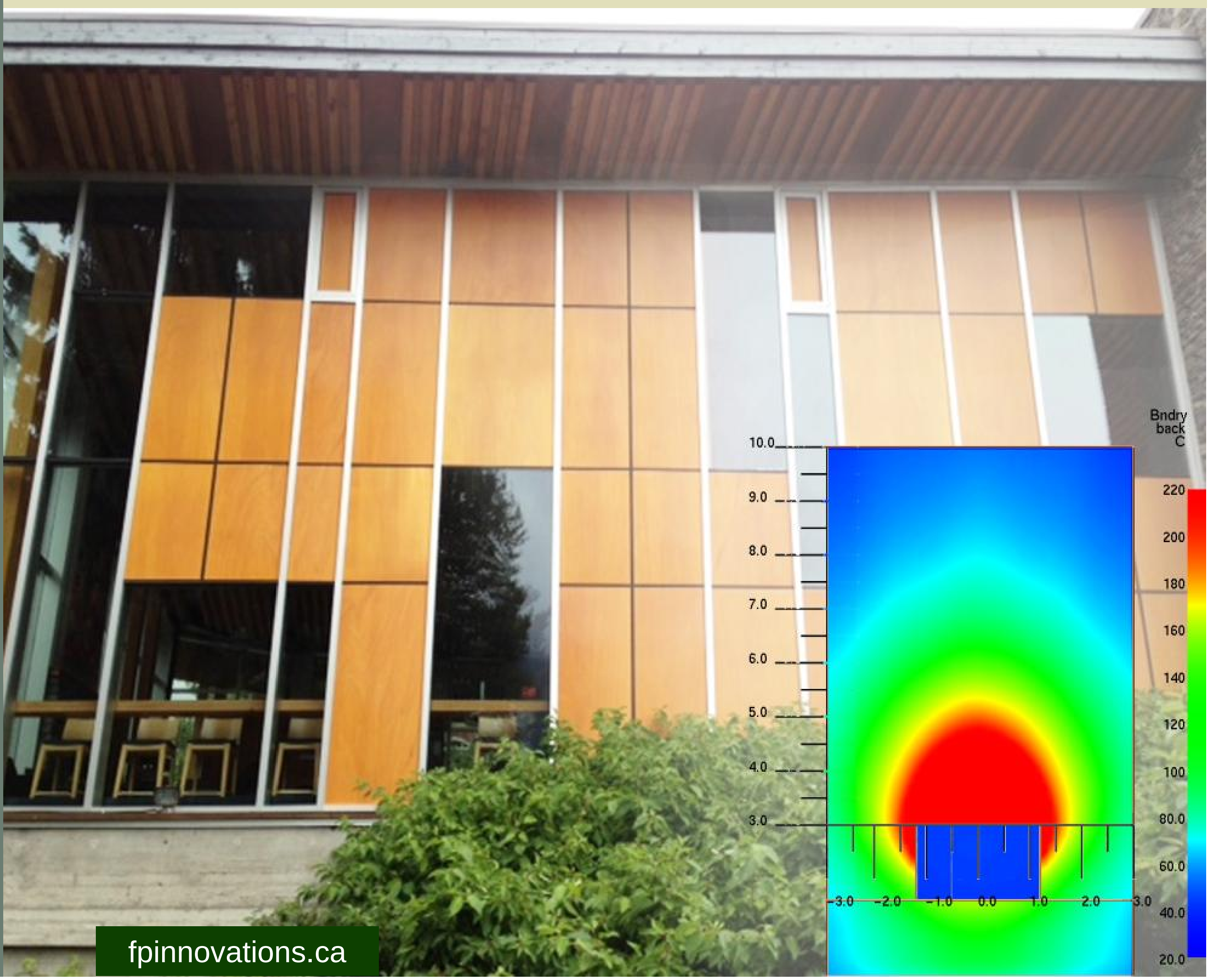

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SUMMARY

The National Building Code of Canada limits the use of combustible materials on buildings required to be constructed of noncombustible construction. Certain combustible materials and configurations are permitted where it can be demonstrated that the material or configuration will insignificantly contribute to fire growth and spread. Combustible exterior cladding materials are permitted based on adequate performance when tested in conformance with CAN/ULC-S134-92, “Standard Method of Fire Test of Exterior Wall Assemblies” (Exterior Wall Test). This test is expensive to conduct and there are few test laboratories that are equipped to conduct the test.

This guide provides a methodology to assess the fire performance of exterior wall assemblies incorporating combustible components using small-scale testing and computerized fluid dynamics based fire models as an alternative approach to conducting the standard test. Small-scale cone calorimeter testing can be used to establish material properties sufficient for input into a fire model. The validity of these inputs can be examined through mid-scale testing and modelling of the mid-scale tests, and discrepancies addressed through additional testing or input parameter derivation.

Once the material properties are appropriately validated, they can be used as input in a model representing the CAN/ULC-S134 test apparatus to establish the performance of the material using the model.

Appropriate documentation is important in defining the design condition, quantifying the stakeholder interests, defining compliance measures, detailing the approach to compliance and guiding future operations, maintenance and alteration of the building incorporating the design to support the alternative approach to compliance.

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1 INTRODUCTION AND SCOPE

1.1 Introduction

The function and capability of computer fire models has evolved to provide excellent predictive simulations of the fire behavior in buildings. The technology provides fire protection engineers with additional scientific-based support in the development of alternative solutions and allows for quantitatively established predictions of fire behavior. This guide provides direction on the appropriate use of fire modelling as a tool to support fire engineering analysis of wood cladding and in-fill wood framing in buildings required to be of noncombustible construction.

For the past 15 years, computer fire modeling has been more readily used to develop performance analysis and technical solutions needed to obtain acceptance of wood design-based solutions following the “equivalency” or objective-based “alternative solution” path, including multiple complex buildings in the Province of BC and in general through many parts of Canada. The fire modeling approaches have been successfully used to obtain approval of both structural and non-structural wood applications where non-combustible construction is normally required, in addition to the use of wood-based cladding systems or other exterior components. Examples of these projects include the Richmond Speed Skating Oval, Surrey City Centre, the Vancouver Convention Centre and Arena Stage in Washington, DC.

The guide provides the foundation to permit greater flexibility for architects/engineers to consider the use of wood in building design, and assist the Authority Having Jurisdiction (AHJ) and/or the appropriate regulatory bodies with acceptance of wood solutions. To a broader extent, the Canadian construction, regulatory and testing industries will also find the contents of this document useful, since it is intended to identify fire modelling as a dynamic and effective tool to analyze building products/systems, which can also keep pace with the rapid rate of change/innovation that exists today.

Figure 1 Wood panels incorporated in exterior window wall assembly of library building, Whistler, BC

1.2 Scope and Limitations

The scope of this guide is to provide technical supporting documentation to the design industry and authorities having jurisdiction to facilitate the use of fire modeling applications relative to the development of advanced wood solutions for buildings. The guide's application is intended for buildings that are required to be constructed as "noncombustible construction" under the NBCC, using the Canadian objective-based alternative solution framework. An overview of the framework and application of the specific requirements being addressed is included as Appendix II.

The scope of this guide is to analyze the current prescriptive requirements of Article 3.1.5.5. "Combustible Components for Exterior Walls" and the referenced fire test standard (CAN/ULC-S134) relative to developing the appropriate alternative solution approaches to building code compliance, using fire modelling as an engineering tool to demonstrate an equal level of performance to that intended by the applicable building codes.

All models have fundamental limitations in their formulation and methodology. This guide assists the user and the reviewer by presenting the technical methodology to using modelling, considering limitations, and supporting a quantitative engineering approach to the development of alternative solutions. The extent to which this quantitative form of analysis is necessary is discretionary depending on the application, and should be coordinated with the designers and the AHJ as part of the overall fire and life safety concepts being developed for a particular project.

In order to demonstrate and elaborate on the application of the computer-based fire modeling methodologies described herein, a new section has been added as Appendix III information considers an example of an exterior wall assembly having a non-load bearing wood-frame in-fill wall provided with 12.7 mm thick fire retardant treated plywood cladding, that is assumed to be installed in a building required to be of noncombustible construction. As an example fire modeling analysis of a wood in-fill exterior wall and cladding assembly, the appendix generally summarizes the material properties, model selection, model validation, model setup and end results as further information to the main contents of this guideline document.

2 NBCC ACCEPTABLE SOLUTION REQUIREMENTS

In considering the development of alternative solutions the following sections of the National Building Code of Canada (NBCC) are considered. Specifically, the NBCC regulates the combustibility of materials permitted in a building required to be constructed of noncombustible construction. The following sections summarize the applicable requirements.

2.1 Material Combustibility

In accordance with Sentence 3.1.5.1.(1), a building or part of a building required to be of noncombustible construction, is required to be constructed with noncombustible materials. However, exemptions are provided in Sentence 3.1.5.2 through 3.1.5.21, 3.1.13.4 and 3.2.2.16 which permit the use of certain minor combustible components.

Sentence 1.4.1.2.(1) of Division A defines noncombustible construction as “that type of construction in which a degree of fire safety is attained by the use of noncombustible materials for structural members and other building assemblies”; and noncombustible material as a “material that meets the acceptance criteria of CAN4-S114, ‘Determination of Non-Combustibility in Building Materials’”.

2.2 Exterior Cladding and Components

In accordance with Sentence 3.1.5.5.(1), except as permitted by Articles 3.2.3.10. and 3.2.3.11., an exterior non-loadbearing wall assembly that includes combustible components is permitted to be used in a building required to be of noncombustible construction provided:

a) the building is

   i) not more than 3 storeys in building height, or
   ii) sprinklered throughout,

b) the interior surfaces of the wall assembly are protected by a thermal barrier conforming to Sentence 3.1.5.12.(3), and

c) the wall assembly satisfies the criteria of Sentences (3) and (4) when subjected to testing in conformance with CAN/ULC-S134, “Standard Method of Fire Test of Exterior Wall Assemblies.”

In accordance with Sentence 3.1.5.5.(3), flaming on or in the wall assembly shall not spread more than 5 m above the opening during or following the test procedure referenced in Sentence (1). The appendix note for this requirement explains that:

> *The maximum flame spread distance refers to the distance between the top of the opening and the highest observable instance of flaming along the wall assembly and thus allows intermittent flaming to a height of 5 m above the opening.*

In accordance with Sentence 3.1.5.5.(4), the heat flux during the flame exposure on a wall assembly shall be not more than 35 kW/m² measured 3.5 m above the opening during the test procedure referenced in Sentence (1). The appendix note for this requirement explains that:

> *The heat flux to the assembly referred to in Sentence (1) is the maximum one-minute averaged heat flux measured by transducers located 3.5 m above the top of the opening. The intent of this criterion is to limit the spread of fire on the wall assembly to a height of 3.5 m above the opening. Since the exact location of flaming on the exterior surface of a wall assembly can be influenced by the presence of furring strips, cavities, etc., in the assembly, which could channel the flame away from a heat flux transducer, sufficient transducers should be located at any given height to intercept any flaming that could occur along the assembly. The exact position of the transducers will depend on the location of cavities, joints, studs or furring strips in the assembly.*

2.3 Objectives, Functional Statements and Intents

The objective of Sentence 3.1.5.1.(1) is to limit the probability of a fire or explosion impacting areas beyond its point of origin [OS1.2] by limiting the severity and effects of fire or explosions [F02]. The intent of Sentence 3.1.5.1.(1) is to limit the probability that building materials will contribute to the growth and spread of fire, which could lead to harm to persons. With regard to exterior wall cladding materials, the intent is to limit the rate of vertical and horizontal fire growth and fire spread beyond the compartment of origin.

There are no objectives and functional statements for Sentence 3.1.5.5.(1). However, the intent of this sentence is to permit the exemption of certain combustible materials from the application of Sentence 3.1.5.1.(1) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth and spread.

3 EXAMPLE APPLICATIONS OF FIRE MODELLING FOR ALTERNATIVE SOLUTIONS

Alternative solutions are often developed and obtained by analyzing the basis of the code requirements, articulating the applicable objectives/functional statements on a qualitative basis, and extrapolating potential fire scenarios for further study. In many cases, this is sufficient to address the stakeholder concerns and more concise qualitative analysis is not needed to satisfy the stakeholders as to the credibility of the approach. Other times, there is greater uncertainty and the use of quantitative analysis can supplement the qualitative analysis and provide more detailed analysis to weigh possible fire development scenarios.

Two examples are included in this section to illustrate applications where the use of fire modelling would provide additional quantitative analysis to support the development of alternative solutions. The first project example is an elementary school building and the second project example is a mid-rise condominium building. It is noted that the referenced alternative solution project examples were developed and proposed utilizing a qualitative analysis process, whereby fire modeling was not applied to the design in order to obtain approval. This was mainly due to the limited application/extent of the proposed combustible exterior elements for each building and early agreement with the AHJ that fire modeling or similar quantitative engineering analysis would not be necessary to demonstrate an equal level of performance for these specific projects.

3.1 Elementary School Project with Combustible Cladding Systems

The school building is a 3 storey, Group A, Division 2 Assembly (school) building. The architectural design of the project incorporates the use of heavy timber wood elements for the roof structure, and the use of exterior wood cladding systems on specific limited areas of the project elevations, which require an alternative solution due to the 3-storey building height (and required noncombustible construction classification).

In this instance, computer fire modelling could be used to show:

1. The extent to which the wood cladding could become exposed to credible fire scenarios, and
2. The extent to which fire spread may be limited by the design configuration of the wood cladding.

Figure 2 Horizontal wood siding incorporated on exterior non-load bearing wall assembly of elementary school building, Vancouver, BC

3.2 Mid-rise Residential Condominium Project with Combustible Cladding Systems

This mid-rise project is required to be constructed of noncombustible construction in accordance with Subsection 3.1.5. and 3.2.2. In order to be consistent with the mountain design aesthetic of the local area, an objective was to incorporate exposed wood cladding/components on the project exterior and the use of in-fill wood-stud exterior wall framing (due to enhanced thermal bridging performance compared with exterior steel studs). An alternative solution is required due to the noncombustible classification.

Computer fire modelling could provide quantitative analysis support an alternative solution by:

1. Evaluating the potential for fire spread and contribution of combustible cladding materials, and
2. The potential temperature rise within the wall cavity which can be used to evaluate the impact of wood studs on the potential for fire spread into the walls.

Figure 3 Exterior wood elements (horizontal siding, roof soffits and heavy timber support structure) of mid-rise condominium building, Whistler, BC

4 ALTERNATIVE SOLUTION APPROACH AND METHODOLOGY

As noted in Section 2.2 of this guide, buildings greater than three storeys in building height that are required to be of noncombustible construction are required to comply with Article 3.1.5.5. This Article requires that the exterior wall cladding material either:

1. meets the NBC definition of "noncombustible"; or
2. satisfies the requirements of Sentences 3.1.5.5.(3) and (4) when tested to CAN/ULC-S134-1992, and the building is required to be "sprinklered throughout".

In accordance with Sentence 1.2.1.1(1) of Division A, compliance with the NBC may be achieved by:

> *complying with the applicable acceptable solutions in Division B... , or using alternative solutions that will achieve at least the minimum level of performance required by Division B in the areas defined by the objectives and functional statements.*

The NBC typically does not provide specific performance criteria relative to complying with the objectives of the Code. The performance of alternative solutions in general is defined in Clause A-1.2.1.1.(1)(b) of Division A, which states that:

> *an effort must be made to demonstrate that an alternative solution will perform as well as a design that would satisfy the applicable acceptable solutions in Division B-not "well enough" but "as well as."*

For purposes of this guide, small scale testing and fire modelling are proposed as an alternative to testing in conformance with the CAN/ULC-S134 test method.

The following sections of this guide summarize the alternative solution approach and methodology.

4.1 Approach to Demonstrating Compliance

The methodology in testing building products as required by building regulatory authorities provides a benchmark for authorities having jurisdiction to accept a product that is tested and listed in accordance with the standard referenced by the building code. However, the test method may not provide results representative of the actual fire-performance. More recent test methods have been developed that would enable modelling of a material to evaluate its fire behaviour as an alternative to full-scale fire testing.

Many of the test methods currently referenced in building codes were developed before the current understanding of the fire performance of building materials was understood within the context of their intended use. The cone-calorimeter is a test apparatus more recently standardized that can provide basic material properties for evaluating the fire performance of a building product. These material properties when utilized in conjunction with appropriately validated modelling approaches provide an estimate of material fire performance.

This modelling methodology is currently being used by the National Institute of Standards and Technology where they have assisted in the evaluation of the growth and behaviour of fire and smoke in several large forensic fire analyses such as the recreation of the fire environment in the World Trade Centre Towers after the aircraft impact [1], Station Night Club Fire in Rhode Island [2], the Cook County Administration Building Fire in Chicago [3], and other smaller fires. These analyses involved a systematic approach to modelling, consistent with the methodology for evaluating the predictive capability of a deterministic fire model within the context of each fire event being modelled. The typical approach for each analysis was:

1. Establishing material properties from cone calorimetry data,
2. Conducting small scale confirmatory testing,
3. Validating derived material properties and model results in comparison with the results from the small scale testing, and
4. Modelling full-scale scenario.

This modelling methodology is not limited to forensic applications, and can be used wherever appropriately validated for the specific purpose in which the model is intended to be used. As a deterministic fire model, it should be noted that the output of the modelling analysis is fully determined by the parameter values and the initial conditions input into the model, without any allowances for random or probabilistic variation.

The purpose of this guide and suggested means of evaluation of exterior walls is to predict the growth and spread of fire in a simulated exterior wall test (CAN/ULC-S134-92, “Standard Method of Fire Test of Exterior Wall Assemblies.") utilizing CFD-based fire modelling and the methodology outlined above. The results of the modelling will be compared with the acceptance criteria for the Exterior Wall Test as outlined in Section 4.5 of this report.

4.2 Performance Criteria

Article 3.1.5.5. is already in performance format to facilitate compliance based on testing in conformance with the CAN/ULC-S134 test method. Therefore, the performance criteria for Sentence 3.1.5.5.(1) are as follows:

- Flaming on or in the wall assembly shall not spread more than 5 m above the opening during or following the test procedure [Sentence 3.1.5.5.(3)].
- The heat flux during the flame exposure on a wall assembly shall be not more than 35 kW/m² measured 3.5 m above the opening during the test procedure [Sentence 3.1.5.5.(4)].

4.3 Phenomena of Interest and Key Physics

The intent of the analysis detailed in this guide is to model the potential contribution of an exterior wall cladding material to the growth and spread of fire up the exterior façade of a building when compared with noncombustible wall cladding. The dominant phenomena of interest in the evaluation of the material is combustibility and flame spread. Analysis of flame spread is a complicated process involving interaction of the thermal, physical and geometrical properties of the material.

As noted in the previous section of this guide, the performance criteria are in terms of flame height and incident heat flux. These are the phenomena of interest and should be considered in terms of key physics relative to appropriate choice of model.

4.4 Appropriate Choice of Model

Model selection depends on the phenomena of interest, key physics and degree of analysis required to adequately demonstrate the objectives (performance criteria) of the building code. Guidance is provided in the SFPE "Guidelines for Substantiating a Fire Model for a Given Application" (the "SFPE Guide"), relative to model selection [4]. The SFPE Guide notes that fire models can be grouped into three categories:

- algebraic models,
- zone or lumped-parameter models, and
- field/computational fluid dynamics (CFD) models.

These model categories are listed in degree of complexity for both underlying physics and capability. The selection of an appropriate model will depend on the model's predictive capability relative to the phenomena of interest and key physics.

As noted in the previous section of this report, the phenomena of interest are combustibility, flame spread, heat flux and flame height. Prediction of these phenomena requires complex underlying physics sensitive to heat transfer, velocity and chemical reactions on small time and geometrical scales. This degree of fidelity and complexity can often only be predicted using field/computational fluid dynamics (CFD) models.

An online survey of models for fire and smoke [5] provides detailed descriptions of model capabilities sufficient to narrow the selection of appropriate models. Several models have the capability to predict the phenomena of interest and key physics associated with combustibility of infill wall systems; however, for purposes of this guide, Fire Dynamics Simulator has been selected.

Note that until CAN/ULC S134 test results are available for calibrating the model, the method may not be applicable to rainscreen walls with drainage cavities, unless the cavities are filled and can be represented by a single solid mass. Further, most currently available models do not have the capability to predict fall-away of material during fire; therefore, all materials are assumed to be static.

4.5 CAN/ULC-S134, "Standard Method of Fire Test of Exterior Wall Assemblies"

This section of the guide provides details of the CAN/ULC-S134-92[1], "Standard Method of Fire Test of Exterior Wall Assemblies" (Exterior Wall Test), upon which appropriate model setup and validation methods can be based.

CAN/ULC-S134-92 is the first edition of a standard prepared and published by the Underwriters' Laboratories of Canada to assess the flame spread characteristics of non-loadbearing exterior wall assemblies by evaluating the:

a) fire spread over the exterior surface;
b) heat flow from the fire plume to the exterior surface; and
c) fire spread within the test specimen.

This test standard does not address "leap-frog" fire spread via window openings or fire spread to adjacent buildings.

4.5.1 Impetus for Standard Development and Testing

An exterior wall fire can result in significant losses by directly damaging the exterior wall or spreading fire to fire compartments above the compartment of origin.

As described in a paper by Oleszkiewicz, regulating authorities are recognizing the development of new combustible cladding systems having economic and aesthetic advantages with limited fire spread characteristics, but are resistant to acceptance of these systems due to the lack of available research.

[1] The 2013 edition is the current version of the CAN/ULC-S134 Test. A similar fire test standard published by NFPA, 285, "Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components". This standard can be used to supplement alternative approaches to compliance for modelling of exterior wall assemblies.

Oleszkiewicz defines the three primary fire threats to the exterior wall of a building as:

1) an interior compartment fire venting through a window;

2) a fire in combustibles accumulated near the wall (burning trash, vehicle fire, bush fire); and

3) a fire in an adjacent building.

Further, Oleszkiewicz notes that the statistically most severe of the above threats is the interior compartment fire venting through a window, resulting from the direct impingement of a fire plume on the outer face of an exterior wall. This ‘primary fire threat’ from the list above is the basis for the development of the CAN/ULC-S134 Test.

4.5.2 Test Setup

The following sections of this report summarize the general dimensions, materials and gas burner configuration for the exterior wall test assembly described in the referenced CAN/ULC standard.

4.5.2.1 General dimensions

The test facility is constructed having a large wall with an adjoining combustion chamber with one opening. The specific test facility dimensions are as follows:

a) the wall is required to extend a minimum of 7 m above the combustion chamber opening;

b) the combustion chamber volume should be at least 60 m^3, with a ratio of the largest to smallest values of the length, width and height not to exceed 2.5 to 1;

c) the combustion chamber opening is limited to 1.4 ± 0.01 m in height and 2.5 ± 0.01 in width, centrally located in the front wall of the chamber so that the top of the opening is in the same horizontal plane as the ceiling of the combustion chamber.

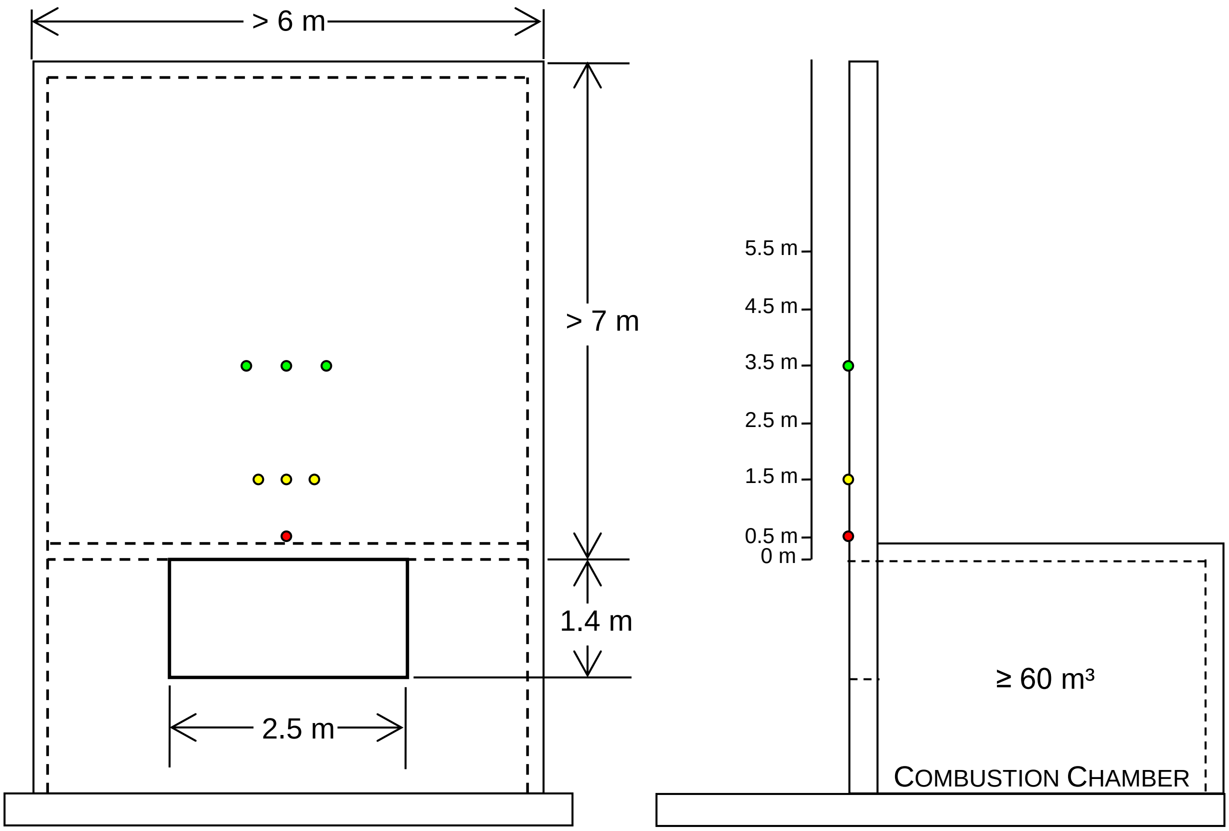


Figure 4 Test facility schematic (not to scale).

4.5.2.2 Materials

The test facility is composed of noncombustible concrete and clay based components with the ceiling and walls of the chamber lined with ceramic fibre insulation.

4.5.2.3 Gas Burner Configuration

The combustion chamber will contain linear gas burners distributed symmetrically in the chamber and elevated above the floor no higher than half way between the floor and the bottom edge of the chamber opening.

4.5.3 Test Specimen and Instrumentation

The test specimen is installed on the front wall of the test assembly with the centre line of the test specimen aligned with the centre line of the combustion chamber opening.

Three liquid-cooled heat flow transducers are located 3.5 ± 0.05 m above the top of the opening, on the same horizontal plane, flush with the exterior surface of the test specimen. The centre transducer is located no more than 0.2 m from the centre line of the combustion chamber opening. The flanking transducers are located 0.5 ± 0.05 m horizontally from the centre transducer. The locations of these transducers are identified by the green circles in Figure 4.

4.5.4 CAN/ULC-S134 Test Apparatus Calibration

The objective of the calibration of the test facility is to establish the mass flow rate of gas that results in specific heat flow values to the wall assembly at specified locations.

A 13 mm mineral composite (marinite) is installed on the front surface of the test assembly. One liquid-cooled heat flow transducer is located on the vertical centre line of the opening, 0.5 ± 0.1 m above the top of the opening. The location of this transducer is identified by the red circle in Figure 4. In addition, three liquid-cooled heat flow transducers are installed 1.5 ± 0.05 m above the top of the opening. The locations of these transducers are identified by the yellow circles in Figure 4. One transducer will be located on the vertical centre line of the opening, with the other two located 0.3 ± 0.05 m horizontally from the centrally located transducer. All of the calibration transducers are located flush with the exterior surface of the mineral composite.

The mass flow rate of the gas supplied to the burners will be adjusted in a linear profile for a 5 minute growth period, followed by a 15 minute steady state period, followed by another 5 minute period of linear decrease to zero as shown in Figure 5.

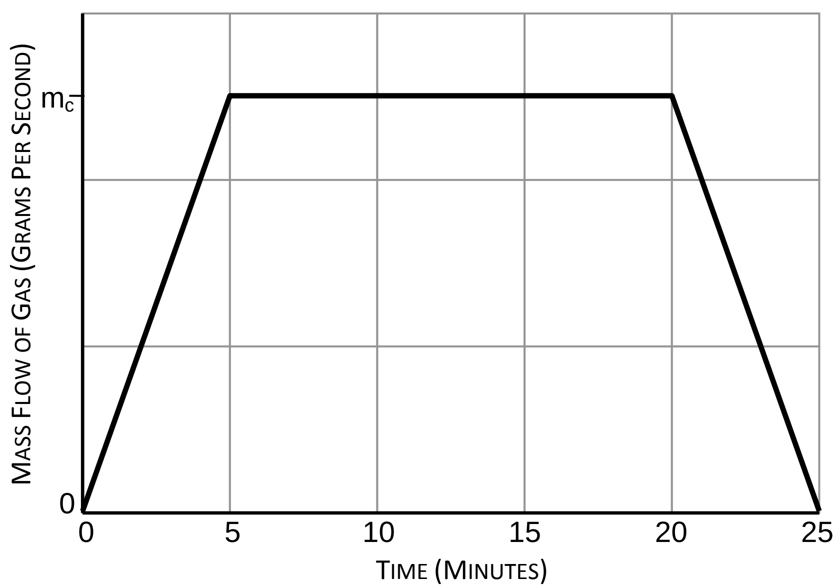


Figure 5 Calibration gas flow rate.

The time average values of the heat flux density, measured by the transducers located 3.5 m above the opening, is calculated over the 15 minute period of steady gas supply. The gas supply is varied for each run until a heat flux density of 45 ± 3 kW/m² at 0.5 m and 27 ± 2 kW/m² at 1.5 m above the top of the opening, calculated as an average over the 15 minute period.

The calibration heat flux density values are representative of a wide range of fire conditions in terms of heat release rate and window dimensions. The exposure levels of 45 and 27 kW/m² were considered by Oleszkiewicz to be representative rather than "worst case" to:

prevent the heat carried by the impinging flame from masking the contribution of the tested wall specimen and making the evaluation of the tested specimen very difficult. An extreme exposing plume is also of little relevance to fire spread on combustible claddings since such a plume would most likely cause spread of fire by windows, irrespective of the wall construction materials.

4.5.5 Test Procedure

The gas supply for the test procedure is identical to that described in the previous section for the calibration procedure with the test specimen mounted on the front surface of the test assembly. The performance of the test specimen is judged based on visual observations and recorded data. The recorded data is averaged over one minute intervals.

4.5.6 Test Results for General Exterior Wall Cladding Materials

Full scale tests of several exterior wall cladding assemblies was conducted by the National Research Council of Canada, consistent with that outlined in CAN/ULC-S134-92, “Standard Method of Fire Test of Exterior Wall Assemblies”. A summary of the test results are included in Table 1 below.

Table 1 Vertical flame spread distance and maximum heat flux densities recorded in full-scale tests.

Assembly		Flame Distance (m)	Heat Flux Density (kW/m²)	
			@ 3.5 m	@ 5.5 m
1	Marinite over concrete block wall	2.0	16	10
2	Gypsum sheathing on glass fiber insulated wood frame wall	3.0	15	10
3.1	Vinyl siding on gypsum sheathing on glass fiber insulation wood frame wall	3.0	23	17
3.2	Aluminum siding on wood chip board on glass fiber insulation wood frame wall	4.5	70	20
3.3	12.7 mm flame retardant treated plywood on untreated wood studs, with phenolic foam insulation in cavities	3.0	29	20
3.4	Aluminum sheet (0.75 mm) on flame retardant treated wood studs, with phenolic foam insulation in cavities	3.2	20	12
3.5	76 mm expanded polystyrene insulation, glass fiber mesh, 7 mm synthetic plaster, on gypsum sheathing, glass fiber insulation steel stud wall	4.5	31	8
3.6	Composite panels (6 mm FRP membranes, 127 mm polyurethane foam core) attached to concrete block wall	4.0	24	10

Assembly		Flame Distance (m)	Heat Flux Density (kW/m²)	
			@ 3.5 m	@ 5.5 m
3.7	102 mm expanded polystyrene insulation bonded to gypsum sheathing, covered with glass fiber mesh embedded in 4 mm synthetic plaster	4.5	48	37
3.8	76 mm expanded polystyrene insulation bonded to gypsum sheathing, covered with glass fiber mesh embedded in 4 mm synthetic plaster	2.0	27	11
4.1	8 mm wood chip board on glass fiber insulated wood frame wall	7.5	61	79
4.2	Vinyl siding on 8 mm wood chip board on glass fiber insulated wood frame wall	7.5	82	111
4.3	Aluminum siding on 25 mm strapping, 25 mm expanded polystyrene, 19 mm plywood, glass fiber insulated wood frame wall	7.5	30	31

The results of the testing in comparison with the acceptance criteria outlined in the NBC indicate that assemblies 3.2, 3.7, and 4.1 to 4.3 (highlighted in yellow) are not acceptable as required by Sentence 3.1.5.5.(1) of the NBC. Whereas the remaining products would be acceptable for use on a multi-storey noncombustible building equipped with an automatic sprinkler system and the interior surfaces of the wall assembly protected with a thermal barrier conforming to Sentence 3.1.5.11.(3). Assemblies 3.1, 3.3 to 3.6, and 3.8 contain combustible material either on the interior of the assembly (e.g. Assembly 3.4) or the exterior face of the assembly (e.g. Assembly 3.3).

The heat flux densities measured on Assembly 1, marinite over a concrete block wall (typically utilized on the exterior face of the test assembly for calibration purposes), were 16 and 10 kW/m² at 3.5 and 5.5 m respectively. These heat flux values are utilized later in this report for the purposes of conducting a sensitivity analysis on a modelled exterior wall test assembly.

4.6 Model Setup and Calibration

Model setup is the process of translating the physical data such as geometry, materials properties, timing, etc. into model input parameters as well as specifying desired output parameters. These are discussed in more detail in the following sections of this guide.

4.6.1 Geometry and Measurement

The Exterior Wall Test model geometry can be constructed based on the dimensions and material properties outlined in the CAN/ULC-S134-92, "Standard Method of Fire Test of Exterior Wall Assemblies", and detailed in Section 4.5.2 of this guide. Specifically, the test standard requires the chamber be constructed as follows:

3.2.1 The floor of the combustion chamber shall be constructed of concrete and shall be covered with fired clay paving stones.

3.2.2 The walls and ceiling of the combustion chamber shall be constructed of concrete, masonry or any combination of materials which will provide and maintain structural integrity, thermal properties and leakage characteristics that are consistent between calibration and test.

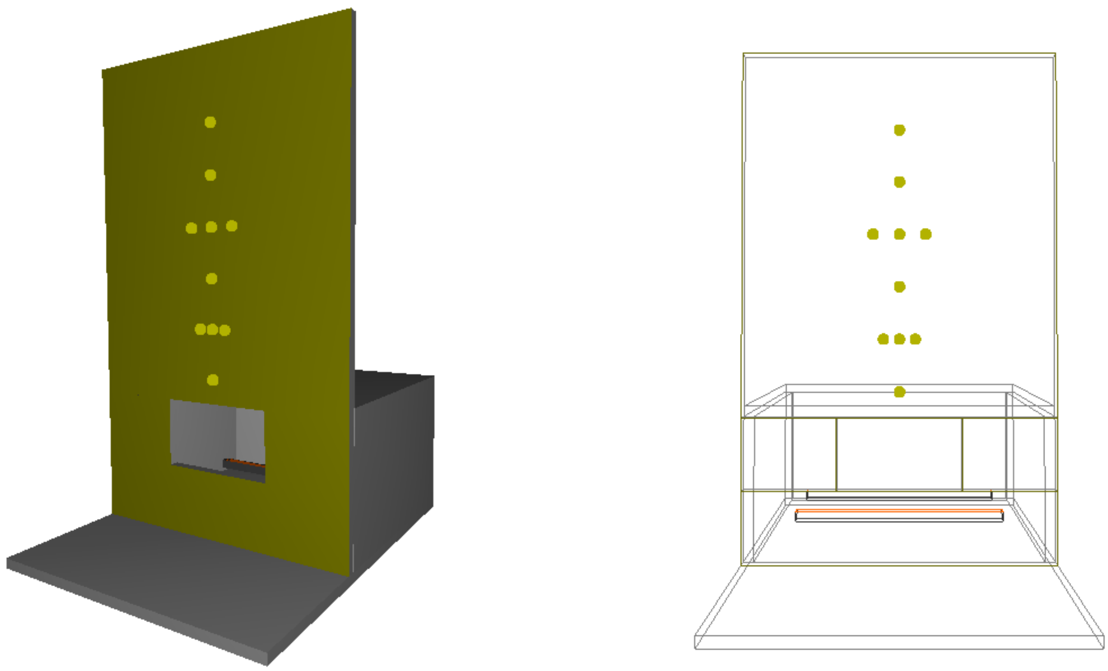
3.2.3 The walls and ceiling of the combustion chamber shall be lined on the room side with nominal 25 mm thick ceramic fibre insulation (nominal density 100 ± 20 kg/m³). The insulation shall extend to the outer edge of the opening of the combustion chamber.

The intent of requiring that the walls and ceiling of the chamber be constructed of concrete or masonry and lined with ceramic fibre insulation is to maintain consistent thermal properties from one test run to the next. It is recommended that model obstructions for the chamber be assigned physical properties consistent with those of the materials specified in the test standard.

In addition to obstructions, measuring devices should be specified in the model input consistent with the type and locations of those specified in the test standard. These are detailed in Section 4.5.2 of this guide.

Grid cell sizing is important to preparing model geometry and the degree of error in the results. Several grid sensitivity studies [6] have shown that refining the grid size leads to a decrease in the discretization error, an error resulting from the numerical solution of the governing equations. The studies evaluated grid cell sizes ranging from 7.5 cm to 1.8 m per grid cell side. The studies examined the change in and accuracy of various model outputs based on comparison with test data and correlation results with changing grid cell sizes and found that the best agreement was obtained with grid cell sizes ranging from 7.5 to 30 cm. The modeller should establish the appropriate grid cell sizing for the application, which may vary depending within the mesh depending on the degree of accuracy sought in each defined grid-spaced region. Reducing grid cell sizes results in increased computation time.

An example of model geometry for the CAN/ULC-S134-92 test apparatus is included in Figure 6 below.



(a) (b)

Figure 6 (a) model isometric view of the exterior wall test apparatus, (b) transparent model front view of exterior wall test apparatus.

4.6.2 Model Calibration

The CAN/ULC-S134 test standard does not specify heat release rate of the exposing fire, but instead recommends that the test apparatus be calibrated to achieve specific radiant heat fluxes at instrument locations. This procedure was outlined in Section 4.5.4 of the guide and can be used to develop a sensitivity regime to address model heat release rate.

Marinite (a noncombustible mineral composite) is specified as the calibration material in the test standard. This same material can be represented, using appropriate input parameters, in the model (see Section 4.6.4 of this guide).

The test standard specifies that the gas supply to the burner be varied until a specific heat flux density of 45 ± 3 kW/m² at 0.5 m and 27 ± 2 kW/m² at 1.5 m above the top of the opening is recorded as an average over the 15 minute period of peak gas flow. In the case of the model, heat release rates can be varied directly. This procedure can be used in the calibration using the marinite. The calibration results can be compared to results obtained from full scale testing of a variety of wall cladding products, including marinite, conducted by NRC [7]. The results of these tests are summarized in Table 1, Section 4.5.6 of this guide, which shows that for marinite, maximum (over 1 minute intervals) heat flux densities of 16 and 10 kW/m² were recorded at 3.5 m and 5.5 m above the opening respectively, and an exposing flame distance of 2 m above the opening.

For the modelling scenario the calibration of the burner will involve varying the HRR until the required heat flux densities are achieved. This will likely require that several models are run with incrementally changing heat release rate values.

4.6.3 Material Properties

Fire models require properties of the material of interest in order to adequately predict the performance of that material under certain conditions. Obtaining appropriate and representative material properties is one of the most critical aspects of fire modelling that can have a significant impact on the reliability of the model results.

In this case, required material properties will include density, thickness, ignition temperature, heat release rate, heat of combustion, thermal-physical properties such as thermal conductivity and/or thermal inertia.

4.6.4 Obtaining Representative Material Properties

ASTM E1591, "Standard Guide for Obtaining Data for Fire Growth Models" [8], provides guidance on appropriate methods that can be used to obtain data as input for fire growth models. The guide is arranged by input parameter, and details procedures that can be used to establish those parameters. For example, the guide recommends that "heat of combustion" be obtained through methods such as combustion bomb calorimetry, cone calorimeter, ICAL apparatus and furniture calorimeter.

Input parameters representing material properties can be obtained either through look-up (i.e., handbooks, technical documents, etc.) or small scale testing. Irrespective of the source of the material properties, it is up to the individual responsible for the modelling analysis to demonstrate that the material properties are sufficiently representative of the actual material.

The following section of this guide details small scale testing using cone calorimetry as an efficient and effectiveness means of obtaining data for input parameters. In addition, methods of analysis are provided where required for certain parameters.

4.6.5 Input Parameters: Cone Calorimetry Testing

As noted in the previous section of this guide, ASTM E1591 recommends methods to obtain input data for fire growth models. Cone calorimetry is one recommended test that provides sufficient data for most modelling scenarios where material properties are required. This is the case for infill wall materials.

Cone calorimetry samples are exposed to specified radiant heat levels, producing the following data:

- Time to Ignition (s)
- Total Weight Loss (g)
- Heat of Combustion (kJ/g)
- Heat Release Rate history (kW/m^2)
- Peak Heat Release Rate (kW/m^2)

- Total Heat (MJ/m^2)
- Peak Smoke Release Rate (m^2/s)
- Total Smoke (m^2)

Some of the data such as Heat Release Rate history or Heat of Combustion can be used as direct input into the model. Other data requires further analysis in order to obtain appropriate input data. These are summarized in the following sections.

4.6.5.1 Ignition Temperature

The procedure for determining the surface temperature required for ignition is as follows:

1) Determine the average time to ignition for each heat flux exposure level.
2) Correlate the average time to ignition by plotting $\left(1/t_{ig}\right)^n$ against the exposure heat fluxes. The value of n is determined based on highest correlation coefficient (R^2) of a linear best fit line, where n is between 0.5 and 1. Where n is closer to 0.5 the material is considered to have thermally thick surface properties. Where n is closer to 1, the material is considered to have thermally thin surface properties.
3) The theoretical critical heat flux for the material coincides with the point at which the line crosses the x-axis. The critical heat flux is the heat flux below which ignition under practical conditions cannot occur.
4) The ignition temperature can be determined by solving the following equation:

$$\varepsilon \cdot q''_{cr} = h_c\left(T_{ig} - T_\infty\right) + \varepsilon \cdot \sigma\left(T_{ig}^4 - T_\infty^4\right) \qquad \text{(Equation 1)}$$

Where (typically):

$$\varepsilon = 1.0$$

$$h_c = 10\,\mathrm{kW/m^2} \cdot K$$

$$\sigma = 5.67 \times 10^{-11}\,\mathrm{kW/m^2} \cdot K^4$$

$$T_\infty = 20\,°C$$

Equation 1 is non-linear; therefore, requires a numerical solution.

4.6.5.2 Thermal Inertia

Defining a material as thermally thin implies that the material will undergo bulk heating in a shorter period of time than if that same material were defined as thermally thick. Most CFD models make certain assumptions and calculations relevant to ignition of the material that depend on how the material is described in the input. Specifically, for a thermally thick material most CFD models conduct a one dimensional heat transfer analysis across the thickness of the material. For a thermally thin material this assumes that the material is the same temperature throughout its depth. In order to eliminate a degree of unknown inherent to the estimation of material heating due to thermal conductivity, and limit additional sensitivity analysis requirements, it is recommended that exterior wall materials be defined in the input as thermally thin.

There are various methods available to derive thermal inertia using cone calorimeter data. These are summarized in a paper by Janssens [9].

4.6.6 Outputs

Sufficient output should be provided to demonstrate that the model is adequately predicting what is intended to predict in support of achieving the objectives of the Code.

Output values are very much model dependant. FDS has a large number of variables that can be tracked and displayed in different modes. The variables include, but are not limited to, temperature, heat flux, velocity, species concentration, burn rate, heat release rate. The FDS Manual provides a detailed list of variables [10]. The variables can be tracked and displayed in the following modes:

- point measurements,
- planar measurements,
- volume measurements,
- surface measurements, and
- 3 dimensional surfaces.

The modes can be measured at points in time, averaged over time ranges or transient. Additional variable functions are available and are listed in the FDS manual [10].

As a minimum, the following is recommended for modelling of the CAN/ULC-S134 Test:

- Incident heat flux at the points specified in the test standard;
- Exterior wall surface temperature;
- burn rate on the exterior wall surface; and
- predicted flame height (isosurface of theorized flame sheet).

4.7 Model Validation

The model constructed to evaluate the Exterior Wall Test is intended to be assessed in terms of quantitative ability to predict the fire growth and spread on the exterior wall surface. This model can be evaluated based on comparison with [11]:

- standard tests,
- full-scale tests conducted specifically for the chosen evaluation,
- previously published full-scale test data,
- documented fire experience, and
- proven benchmark models.

The modelling analysis of the Exterior Wall Test can be evaluated based on comparison with appropriate small and mid-scale tests and previously published full-scale test data from CAN/ULC-S134 tests.

In quantifying model evaluation ASTM E1355 recommends that “the necessary and perceived level of agreement for any predicted quantity is dependent upon the typical use of the quantity in the context of the specific use being evaluated, the nature of the comparison, and the context of the comparison in relation to other comparisons being made.” For steady state or near steady state comparisons it is recommended that the comparison be expressed as an average absolute difference or average relative difference.

The exterior wall test is a near steady state evaluation summarized as an average heat flux density quantity at various locations on the exterior wall surface. Therefore, results of a model evaluation of infill wall product/material can be presented as an average absolute difference.

ASTM E1355 defines a sensitivity analysis of a model as “a study of how changes in model parameters affect the results generated by the model.” The purpose of conducting a sensitivity analysis is to assess the extent to which uncertainty in model inputs is manifested to become uncertainty in the results of interest from the model.

The approach to analysis in evaluating infill wall assemblies in conformance with CAN/ULC-S134 involves calibrating the model performance based on the calibration procedure outlined in the exterior wall test standard. The calibration is dependent on the heat flux density on the surface of the exterior wall, which is directly related to the heat release rate (HRR) of the compartment burner, which is not defined in the test standard. The effect of changing the burner HRR on the results of the model predictions is unknown, and should be incorporated into the model evaluation by varying the burner HRR for consecutive runs of the model in establishing the calibration parameters.

4.7.1 Mid-Scale Testing

Mid-scale testing can be used to demonstrate that the derived model inputs represent the material they are intended to represent. The decision to conduct a mid-scale test and choice of test are dependent on the level of confidence in the derived material input parameters. This is a decision that should be agreed-upon by all stakeholders prior to conducting full-scale modelling.

The process of validation using mid-scale testing is proposed as follows:

1) Obtain material properties from small scale testing,
2) Select mid-scale testing appropriate for material of interest,
3) Identify key metrics in mid-scale test for comparison with a model of the mid-scale test,
4) Construct a model of the mid-scale test,

5) Run mid-scale test model,
6) Compare model outputs with test outputs.

These steps can be re-organized if a need for blind study comparison is required. In that case, modelling should be completed prior to running of the actual mid-scale test.

Any discrepancies between the mid-scale test results and model result should be quantified and addressed through either refinement of the small-scale testing and input parameter derivation, or development of sensitivity analyses that address the variable(s) of concerns by examining a range of values covering any discrepancies between test and model.

5 DOCUMENTATION

Appropriate documentation is important in defining the design condition, quantifying the stakeholder interests, defining compliance measures, detailing the approach to compliance and guiding future operations, maintenance and alteration of the building incorporating the design.

In the case of exterior wall assemblies, where compliance with Part 3 is sought, in conformance with Sentence 2.2.7.1.(1) of Division C the NBC requires professional design and review.

The following sections of this guide summarize qualifications, design brief, final report and operations and maintenance considerations.

5.1 Qualifications

The individual or team members preparing the design should have sufficient knowledge and experience in the relevant subject matter. Specifically, in accordance with Sentence 2.3.1.1.(4) of Division C:

> *information about the qualifications, experience and background of the person or persons taking responsibility for the design [be submitted].*

The design professional should submit sufficient documentation, such as a CV, summarizing their knowledge and experience relative to the subject matter of the design. This is required to be documented by Sentence 2.3.1.1.(4) of Division C of the Code. In demonstrating qualifications, the following information is recommended:

- Education
- Experience, particularly related to the preparation of alternative solutions
- Certifications and licenses
- References

The extent of documentation required to demonstrate an individual’s qualifications in preparing the design should be proportional to the complexity of the design and the methodologies used to demonstrate compliance.

5.2 Design Brief

Defining the conceptual approach to compliance is important to the success of an alternative solution design based on fire modelling design analysis. The conceptual approach should be defined early in the design process and establishes an agreement between stakeholders and sets the framework for the preparation and review of the design based on that agreement.

The extent of documentation required to convey the design is proportional to the complexity of the analysis in support of the design. In this case, the alternative solution relies on complex fire modelling to demonstrate an equivalent level of performance. The following steps are recommended for the proposed level of complexity; however, should be discussed with project stakeholders [12]:

1) define project scope,
2) identify goals,
3) define objectives,
4) develop performance criteria,
5) develop trial designs,
6) evaluate trial designs and select final designs,
7) select final design (provided the trial design meets the performance criteria), and
8) prepare design documents.

These steps are discussed in more details in the following sections.

5.2.1 Defining Project Scope

This step involves identifying information pertinent to initiating the design including the applicable regulatory requirements, project stakeholders, material and design characteristics, the intended use and occupancy of the building on which the exterior wall will be located, and project schedule. This is the initiating step in the process.

5.2.2 Identifying Goals

This step involves identification and documentation of the goals to seek concurrence with the project stakeholders. The stakeholder group typically includes, but is not limited to, the building owner, design team and Authority Having Jurisdiction.

A team-based approach is crucial to the success of the project at this stage and can be achieved through identification and agreement of the goals considered most important to the stakeholders. This will assist in defining objectives, performance criteria and design methodologies and limit problems later in the design process.

5.2.3 Define Objectives

Objectives are a refinement of the design goals in a manner that can be quantified and by which performance criteria can be developed. This step involves identification and agreement of the applicable primary and associated sub-objectives of the Code.

5.2.4 Develop Performance Criteria

Performance criteria are developed by further refinement of the objectives into numerical values by which the trial designs can be compared. This step requires agreement between the designers and the Authority Having Jurisdiction relative to the intent of the Code and how the chosen numerical values demonstrate achievement of the Code's objectives. As mentioned previously, the performance criteria associated with Article 3.1.5.5. are quite clear.

5.2.5 Develop Analysis Approach

Development of an analysis approach is key to obtaining buy-in by all stakeholders. Development of a design approach should:

- describe the steps to achieve the objectives of the code and demonstrate performance,
- define key risk factors to be addressed by analysis,
- define methods and calculations used to demonstrate performance and the appropriateness of these methods and calculations for the intended purpose,
- describe the intended means of reporting on the outcome of the analysis.

5.2.6 Prepare Design Documents

Design documents include all of the information outlined above and will assist stakeholders in identifying what is required in order to review, implement, maintain and potentially alter alternative solution designs.

5.3 Final Report

The NBCC has specific requirements relative to documentation of alternative solutions, including:

- a code analysis outlining the analytical methods and rationales used to determine that a proposed alternative solution will achieve at least the level of performance required by the Code [Division C, Clause 2.3.1.1.(2)(a)];

- the applicable acceptable solution requirements, objectives and functional statements be identified [Division C, Sentence 2.3.1.1.(3)];

- assumptions, limiting or restricting factors, testing procedures, engineering studies or building performance parameters supporting the alternative solution(s) [Division C, Sentence 2.3.1.1.(3)];

- sufficient detail to convey the design intent and to support the validity, accuracy, relevance and precision of the alternative solution approach(es) [Division C, Sentence 2.3.1.1.(5)];

- qualifications, experience and background of the person or persons taking responsibility for the design [Division C, Sentence 2.3.1.1.(4)]; and,

- special maintenance or operational requirements including any building component commissioning requirements that are necessary for the alternative solution to achieve compliance with the Code after the building is constructed [Division C, Sentence 2.3.1.1.(2)(b)].

The purpose of preparing a report outlining the analysis is to adequately convey to the stakeholder group that the design has performed, within the framework proposed in the design brief, and should convey sufficient information to demonstrate to the stakeholders and the Authority Having Jurisdiction that the alternative design will comply with the objectives of the Code.

The report should be comprehensive and address the specifics of the code alternative solutions. The use of fire modelling is a complement and not a substitute for providing qualitative assessment of the scenarios being analyzed. The details of the code requirements, limitations of the modelling analysis, and purveyance of expertise and judgment should accompany a quantitative analysis.

5.4 Operations and Maintenance

Upon acceptance, an alternative solution design is considered compliant with the Code, and should be maintained in compliance with the Code under which it was approved. Retention of the alternative solution documentation by the Authority Having Jurisdiction is important beyond just compliance for the following reasons, as outlined in Appendix Note A-2.3.1. of Division C:

- *Documentation helps consultants perform code compliance assessments of existing buildings before they are sold and informs current owners or prospective buyers of existing buildings of any limitations pertaining to their future use or development.*

- *Documentation provides design professionals with the basic information necessary to design changes to an existing building. An alternative solution could be invalidated by a proposed alteration to a building. Designers and regulators must therefore know the details of the particular alternative solutions that were integral to the original design. Complete documentation should provide insight as to why one alternative solution was chosen over another.*

- *Documentation is the "paper trail" of the alternative solution negotiated between the designer and the regulator and should demonstrate that a rational process led to the acceptance of the alternative solution as an equivalency.*

- *It is possible that over time a particular alternative solution may be shown to be inadequate. It would be advantageous for a jurisdiction to know which buildings included that alternative solution as part of their design: documentation will facilitate this type of analysis.*

- *Project documentation provides important information to a forensic team that is called to investigate an accident or why a design failed to provide the level of performance expected.*

These should be considered relative to the development of any operations and maintenance strategies.

6 CONCLUDING REMARKS

This guide provides direction on developing alternative solutions for in-fill walls and combustible cladding using computer fire modelling. The NBCC permits alternative solutions in Division A of the Code and an alternative solution is a code-complying path to demonstrating compliance with the objectives of the Code. Computer fire modelling provides an engineering-based approach to quantify fire behavior and supplement qualitative analysis of alternative designs where stakeholders (designers and authorities) determine that this level of technical study is warranted.

This guide defines a path to developing alternative solutions using computer fire modelling with the following critical steps and/or inputs as part of the complete modeling analysis:

1. Define the requirements in Division B where the alternative solution is being sought.

2. Establish the Objectives, Functional Statements and Intents of the Division B requirements and qualify the methodology and approach to analyzing the fire performance of the wood materials and construction method.

3. Establish the measureable performance criteria. As an example, the technical basis for the exterior cladding fire test (ULC S134) was developed to illustrate how measureable performance criteria can be developed and compared with other materials. This is one useful basis of comparison for evaluating the performance of cladding and in-fill materials in exterior walls.

4. Establish modelling input values through testing or published literature. Although considerable data is published, it is not always in the form where it can be readily input into a fire model. Small-scale testing using a cone calorimeter can serve as the foundation to derive the material properties.

5. Prepare a design brief that outlines the method of study and the performance/acceptance criteria for review by the stakeholders. This allows for feedback and input from interested parties to establish the range of parameters and measureable performance criteria to be considered, and provides the basis for accepting the results of the modelling once complete.

6. Construct the models and calibrate the performance by comparing results with known materials or comparing results against published tests. In this step, the model should be programmed to measure all of the parameters of interest in order to quantify that the performance can be achieved. In the example provided, results from a series of full-scale tests from different materials can be used as a basis of comparison if modelling the ULC S134 test. Calibration of the initiating fire will require a lower and upper bound of simulations to account for uncertainty in the heat release rate output from the heptane pan. In some cases, this is the precursory step to demonstrating the performance of the model and the end-configuration of the wood installation needs to be studied for the specific project.

7. Summarize the output of the analysis in fire modelling report for review by the stakeholders. This report should demonstrate that the performance criteria was achieved and therefore, the configuration of the wood in-fill or cladding system will achieve the required level of fire

performance relative to the objectives of the Code. This report is either a stand-alone document that can be referred to, or is directly integrated as the alternative solution report.

As with any modelling, appropriate application and input of the model defines will define the usefulness of the results. Modelling requires the appropriate level of expertise and experience to complete reliably and efficiently. As our codes become more performance-oriented, the opportunities to interface wood into the construction become more viable where additional technical justification substantiates the opportunity.

7 REFERENCES

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Appendix I Guideline Review Ranking System[1]

The following ranking system has been developed to monitor the status of the wood building design guidelines[2] maintained by the BC Advisory Group on Advanced Wood Design Solutions (AGW):

RANK	DEFINITION
#	This is a draft document this is being circulated for review and comments.
A	This guideline is new and represents the best available evidence at this time. It will be periodically reviewed to determine if it remains current.
B	This guideline was last reviewed on the date indicated and there have been new studies published since the guideline was developed. However, the AGW determined that these studies are not sufficient to warrant changing the guideline. The information contained in this guideline provides the user with the best evidence available at the time the guideline was published. Readers are encouraged to search the current literature as a supplement to using this guideline.
C	This guideline was last reviewed on the date indicated. As a result of that review, the AGW determined that new studies have been published that warrant an update of the chapter/section of this practice guideline. The AGW also determined that the remainder of the chapters/sections does not require updating and these recommendations remain current.
D	This guideline was last reviewed on the date indicated. As a result of that review, the AGW determined that new data are available that are sufficient to potentially change guideline recommend and a full revision is warranted.
E	This guideline was last reviewed on the date indicated. As a result of that review, the AGW decided it is outdated; however, it has been retained for historical and/or educational purposes. These guidelines should be used with caution for design purposes.

[1] This list was adapted from the Canadian Thoracic Society Policy and Evidence-Based Medicine, and the American College of Chest Physicians (ACCP) Guidelines Ranking System.
[2] Check fpinnovations.ca for the latest edition.

Appendix II Background on Alternative Solutions

The Objective-based National Building Code of Canada (NBCC) was first introduced and published in 2005, and has become the basis for future editions of the NBCC in its current format. The NBCC provides building designers and review authorities two separate paths to achieve code compliance; a prescriptive path referred to as “acceptable solutions” (similar to pre-2005 Code format), and an objective-based path referred to as “alternative solutions.” The objective-based Code format including the use of alternative solutions was developed by the National Research Council of Canada, in consultation with industry representatives, to allow more flexibility and innovation to be introduced in the application of building code requirements, and to provide a greater source of information and more transparency in the development and review of possible alternative solutions.

The NBCC is made up of two major divisions: Division A and Division B. Division A presents the objectives that the code addresses and the functional requirements (in qualitative terms) that alternative solutions must satisfy. Division B presents the quantitative criteria with which alternative solutions must comply (where these are available) and provide deemed-to-comply “acceptable solutions” drawn from the current version of the Building Code.

The NBCC explains that compliance with the Code can be achieved by:

- complying with the applicable acceptable solutions in Division B, or
- using alternative solutions that will achieve at least the minimum level of performance required by Division B in the areas defined by the objectives and functional statements attributed to the applicable acceptable solutions.

The document also includes an entire list of Objective Statements, categorized as:

- OS - Safety,
- OH - Health,
- OA - Accessibility, and
- OP - Fire and Structural Protection of Buildings,

and the corresponding sub-objectives.

Included as part of the model NBCC document is the list of Functional Statements, which are measures, such as those described in the acceptable solutions in Division B, that are intended to allow the building or its elements to achieve the stated objectives.

Finally, the NBCC includes a list of the attribution to the Acceptable Solutions where the objective and functional statements attributed to each existing code requirement (i.e., Division B) are listed against the code reference.

II.1 Formulation of Alternative Solutions

The Appendix to the NBCC provides guidance for the development of alternative solutions. First of all, the proponent of an alternative solution must demonstrate that the alternative solution addresses the same issues as the applicable acceptable solutions in Division B, and their attributed objectives and functional statements. Furthermore, effort must be made to demonstrate that an alternative solution will perform as well as a design that would satisfy the applicable acceptable solutions in Division B. In this sense, it is Division B that defines the boundaries between acceptable risks and the “unacceptable” risks referred to in the objective statements.

When Division B offers a choice between several possible designs, the one meeting the “baseline” level of performance should generally be considered to establish the minimum acceptable level of performance to be used in evaluating alternative solutions for compliance with the code. The main issue or difficulty with developing innovative “wood-based” alternative solutions (i.e., alternative solutions to use wood elements where not specifically permitted for a noncombustible building), is that often the AHJ/building regulators will use the reference acceptable solutions, or prescriptive requirements, as a measuring stick to determine if the proposed alternative solution is deemed to perform “as good as” the building code requirement(s) it is intended to replace.

An example of this would be an alternative solution proposal to use wood cladding/components on the exterior of a building required to be of noncombustible construction (and hence requiring noncombustible exterior cladding/components). In many cases, it is illogical to the building regulation community to say that a combustible wood element will perform as good as a noncombustible element, and the onus is on the FPE and design team to develop an alternative solution that demonstrates an equal level of fire safety, on a performance basis.

As the later sections of this report will illustrate further, the application of fire modeling methodologies can be an essential part of a fire safety/fire dynamics analysis, which can ultimately address the unknown factors associated with use of combustible materials/systems in building environments, using a comprehensive performance-based approach to building code compliance. It must also be mentioned that the building code requires authors/developers of alternative solutions to outline their qualifications and experience relative to the alternative solutions being proposed. With any alternative solutions relying on fire/smoke modeling or similar computer analysis applications, the necessary professional qualifications, experience and judgment must also be provided, commensurate with the scope of the modeling analysis being performed.

II.2 Objective-Based Framework

Prior to the 2005 NBCC edition, the existing model Code structure did not easily facilitate the incorporation of new information that is provided with performance or objective-based codes, such as related objectives, functional statements and intent or application background information. Most of this information was either not readily available or had not developed for reference by general Code users. The new model NBCC structure and format was developed to include the current technical provisions of the Code (in the form of specific Code requirements), but was essentially restructured to create a new Code framework around the following 3 divisions:

Division A: Compliance, Objectives and Functional Statements - New information incorporated in the NBCC that was specifically developed to facilitate the objective-based format. Since the objective and functional statements of Division A are not expected to change on a regular basis, it is noted that the contents of Division A will not generally be updated with each new edition of the Codes.

Division B: Acceptable Solutions - Mainly the existing Codes' technical requirements and specific provisions to be incorporated in building design relative to safety, health, barrier-free accessibility, and fire/structural performance of buildings. Division B was also developed to reference the associated objectives and functional statements that each specific technical requirement is deemed to satisfy, with the purpose that every acceptable solution is linked to at least one of the applicable objectives and functional statements. Since the requirements associated with Division B will be updated as part of the regular Code development and review process (i.e., every 5 year Code cycle), it is expected that the contents of Division B will be updated with each new Code edition (i.e., new code change proposals or modifications to existing acceptable solutions).

Division C: Administrative Provisions - This Division was developed to contain the administrative provisions that were previously included in Part 1 or 2 of the model Code, with the purpose that a separate division would facilitate the replacement or revision of these provisions with other provincial or territorial administrative provisions.

II.2.1 Acceptable Solutions

Division B of the model Code contains the applicable technical requirements and specific provisions to be incorporated in building design relative to safety, health, barrier-free accessibility, and fire/structural performance of buildings. Division B also references the associated objectives and functional statements that each specific technical requirement is deemed to satisfy, with the purpose that every acceptable solution is linked to at least one of the applicable objectives and functional statements.

For example, the technical "acceptable solution" requirements associated with the use of combustible cladding or components in an exterior wall assembly of a building required to be of noncombustible construction (as determined by the applicable Subsection 3.2.2. requirements) are referenced in Subsection 3.1.5., and specifically Article 3.1.5.5. (refer to Section 2.2 of this report for a complete excerpt of this technical requirement). It is noted that the acceptable solutions incorporated in Division B are considered a key component in the development of a sound alternative solution approach, since the technical requirements of Division B provide a "measuring stick" or comparative benchmark for the level of performance to be achieved in the ultimate alternative solution proposal for a given design problem. This aspect of alternative solution analysis and development will be discussed further in the following sections of this report.

II.2.2 Objectives and Functional Statements

The other key components of the objective-based Code format that were introduced in 2005 and carried forward to the current 2010 edition, are the terms "objectives" and "functional statements" which were developed to provide additional information relative to the basis for each technical requirement, as follows:

<u>Objectives</u>: the objective statements were developed to state what the objective of a specific Code provision, or what the requirement aims to achieve in its application. The objectives referenced in the Code provide definition to a specific Code provision, and is also intended to provide the "rationale" behind the stated acceptable solution in Division B. The fundamental objectives developed the CCBFC for the model NBCC are broken down into the following categories:

- Safety
- Health
- Accessibility
- Fire and Structural Protection of Buildings

It is also noted that additional objectives related to Fire Protection of Buildings and Facilities are referenced with the acceptable solutions incorporated in the National Fire Code of Canada.

The objectives associated with each technical requirement of the Acceptable Solutions – Division B are found in Part A of the NBCC, including the second level sub-objectives associated with the "Safety" objective: Fire Safety, Structural Safety, Safety in Use, Resistance to Unwanted Entry, and Safety at Construction and Demolition Sites.

Functional Statements: the functional statements go "hand-in-hand" with the related objective-statements and are intended to translate the objectives into operational terms. Functional statements describe the general conditions to be achieved in qualitative terms and generally describe the outcome required, but not necessarily how to achieve that outcome (which is left up to the individual developing an alternative solution proposal). In this regard, functional statements may be useful in the evaluation process of a proposed alternative solution concept for a given design problem.

Specific Objective and Functional Statements for Article 3.1.5.5.

Relative to the technical requirements of Article 3.1.5.5., it is noted that specific objective and functional statements have not been published for each particular "combustible element in noncombustible building" provision. However, it is noted that general objective and functional statements attributed to the acceptable solutions of Sentence 3.1.5.1.(1) "Noncombustible Materials" have been published, as outlined below (**F02-OS1.2 and F02-OP1.2**):

Objective OS1.2 – OS is a "safety" objective which states "an objective of this Code is to limit the probability that, as a result of the design, construction or demolition of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury."

The specific objective of OS1.2 is stated as "an objective of this Code is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in this Code are those caused by – fire or explosion impacting areas beyond its point of origin."

Objective OP1.2 – OP is a "fire and structural protection of buildings" objective which states "an objective of this Code is to limit the probability that, as a result of the design, construction or demolition of the building, the building or adjacent buildings will be exposed to an unacceptable risk of damage due to fire or structural insufficiency, or the building or part thereof will be exposed to an unacceptable risk or loss of use also due to structural insufficiency."

The specific objective of OP1.2 is stated as "an objective of this Code is to limit the probability that, as a result of the design or construction, the building will be exposed to an unacceptable risk of damage due to fire. The risks of damage due to fire addressed in this Code are those caused by – fire or explosion impacting areas beyond its point of origin."

Functional Statement F02 – Sentence 3.2.1.1.(1) of Division A states, “The objectives of this Code are achieved by measures, such as those described in the acceptable solutions in Division B, that are intended to allow the building or its elements to perform the following functions:

F02: To limit the severity and effects of fire or explosions.

The listing of functional statements is intended to “group” each function into functions that deal with closely related subjects, and in the instance of F02, this functional statement is part of a group that is intended to address “fire risks”.

II.2.3 Intent Statements

The intent statements associated with each Code requirement have been published by CCBFC to provide additional background information on what each Code provision aims to achieve, and explains the link between an acceptable solution and it’s attributed objectives and functional statements. This explanatory information is not considered part of the model Code, but accessory information to assist Code users to evaluate and understand the acceptable solutions, as they are developing an alternative solution proposal. The use of intent statements in Code analysis and application will generally lead towards a more consistent application of the technical requirements of Division B.

Application statements are also available with the intent statements mentioned above, and these application statements are intended to describe the situations to which each Code provision may apply or may not apply.

The intent statements associated with the technical requirements of Sentence 3.1.5.1.(1) and Article 3.1.5.5. are as follows:

3.1.5.1.(1) – Intent 1: To clarify what constitutes noncombustible construction.

3.1.5.1.(1) – Intent 2: To limit the probability that construction materials will contribute to the growth and spread of fire, which could lead to harm to persons.

3.1.5.5.(1) – Intent 1: To exempt certain combustible materials from the application of Sentence 3.1.5.1.(1) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth or spread.

3.1.5.5.(1) – Intent 2: To state the application of Sentences 3.1.5.5.(2) and (3).

3.1.5.5.(2) – Intent 1: To exempt certain combustible materials from the application of Sentence 3.1.5.1.(1) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth or spread.

3.1.5.5.(3) – Intent 1: To exempt certain combustible materials from the application of Sentence 3.1.5.1.(1) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth or spread.

3.1.5.5.(4) – Intent 1: To clarify that the wall assembly must be subjected to weathering tests before the fire tests to limit the probability that the weathering of the material will negatively affect its ability to minimize fire growth or spread.

General Discussion of Code Intent of Article 3.1.5.5.

In general, most technical fire safety requirements of Division B of the NBCC describe how the code's objectives and functional statements are achieved. However, some requirements, such as Article 3.1.5.5., do not relate directly to a code objective or functional statement. As noted in the intent statements, the intent of this provision is to exempt certain combustible materials from the application of Sentence 3.1.5.1.(1) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth and spread.

The general intent of the noncombustible construction requirements is to attain a higher degree of fire safety relative to buildings of "combustible construction" and to reduce the probability that a potential fire in a building will result in fire spread, damage or injury through the involvement of combustible construction materials. Combustible construction assemblies can contribute to the growth and spread of fire within the building, which could increase the fire hazard to its occupants and hinder fire fighting operations.

The intent of permitting specific combustible materials to be incorporated or utilized in buildings of noncombustible construction (in accordance with Subsection 3.1.5.) is partially based on standard construction practices (i.e., using wood for exterior roofing or interior blocking) and providing greater flexibility and more cost-effective methods for typical construction assemblies such as roof/wall assemblies, interior finishes, backing/nailing surfaces, etc. These specific combustible materials are also permitted to be used in noncombustible buildings, based on the assumption that they have a limited impact on the fire and life safety performance of a building as a whole.

The intent of limiting combustible components and cladding in exterior walls of a building required to be of noncombustible construction, is also to reduce the probability that a fire originating in the building will spread to the exterior, which could then further spread to the storeys above by direct flame extension from the compartment of origin, or by indirect combustion and vertical burning of the exterior materials resulting in "laddering" of a fire event on the exterior elevation of the building.

It is generally understood in the design and regulatory community that the risk of fire spread from an interior fire compartment horizontally through to the exterior façade/wall construction or vertically via the dynamics of flame leap, creates a potential concern relative to buildings of combustible construction or higher buildings of noncombustible construction. One example of where this issue has been addressed to some extent is the changes to the B.C. Building Code (BCBC) in 2011 to permit 5-6 storeys of combustible construction for residential (Group C) type occupancies. With this change, the BCBC incorporated new requirements for the exterior cladding of exterior wall assemblies (under the assumption that these would be wood-frame), to permit either i) noncombustible cladding, ii) fire-retardant treated wood cladding (FRTW), or iii) a cladding system where the wall assembly satisfies the criteria of Sentences (3) and (4) when subjected to testing in conformance with CAN/ULC-S134, "Standard Method of Fire Test of Exterior Wall Assemblies."

Of interest to the above requirements developed for 5-6 storey wood frame residential buildings, is that the majority of projects being constructed in B.C. are utilizing the “noncombustible cladding” option for code compliance, as FRTW cladding systems are not readily available or cost-effective in use, and there are currently no wood-frame exterior wall/cladding systems that have been tested to the CAN/ULC-S134 standard. The other point to note relative to the new exterior wall/cladding system requirements for wood-frame residential buildings, is that while the issue of cladding combustibility has been regulated, these requirements do not provide any clear guidance or requirements relative to other architectural treatments that are typically used on exterior building design, such as canopies, fascias, soffits, trims and similar features.

Appendix III Fire Modelling Example for an Exterior Wall Assembly

All material properties and data used in this example are provided for purposes of illustrating the methodology outlined in this Guide and are not intended to be utilized for purposes of design. It is incumbent on users of this Guide to demonstrate appropriateness of material data for purposes of design, including the material data included in this example.

III.1 Introduction and Example Material Description

This example considers the use of an exterior wall cladding having a 12.7 mm thick fire retardant treated southern pine plywood surfaced wood frame wall. The wall is intended to be used on a building required to be constructed of noncombustible construction. Therefore, in accordance with Sentence 3.1.5.5.(1), the exterior wall is required to meet certain performance criteria when tested in conformance with the CAN/ULC-S134 test. However, as introduced and discussed in the main sections of this document, it is proposed to utilize the methodology outlined in this Guide as an alternative to the CAN/ULC-S134 test.

The following sections of this appendix summarize the material properties, model selection, model validation, model setup and results.

III.2 Material Properties

As noted in Section 4.2 of this report, the performance criteria for the CAN/ULC-S134 test are flame height and heat flux. These factors relate to the potential contribution of an exterior cladding material to the growth and spread of fire. The phenomenon of interest is flame spread, which is a function of the incident radiant heat flux upon the cladding surface and the material response to heating.

The incident radiant heat flux is established based on calibration of the fuel source in the test apparatus and is independent of the type of cladding material. The material response to heating is a function of the following:

- Ignition energy expressed as a temperature;
- Thermal properties including conduction, heat capacity and density;
- Heat of combustion; and,
- Energy release rate and duration following ignition.

As noted in Section 4.6.5 of this Guide, cone calorimetry is one of the methods recommended by ASTM E1591 for obtaining all of the data detailed above.

III.2.1 Representative Cone Calorimeter Data

It is important to either complete cone calorimeter tests based on increasing incident heat flux exposures or select a set of data representing increasing heat flux exposures. This is required in order to calculate the ignition temperatures of the material from the calorimetry data. In addition, the test heat flux exposures should bound the heat flux of interest in order to obtain representative physical properties of the material at that flux. In this case, the CAN/ULC-S134 test apparatus is calibrated to expose the material to a heat flux of 45 kW/m² at 0.5 m above the opening and 27 kW/m² at 1.5 m above the opening and expected to lessen with height. The resulting set of data should therefore bound these heat flux exposures.

Cone calorimeter data can either be obtained from conducting tests or utilizing pre-existing test data. Note that if using pre-existing test data, it is important to demonstrate that the data is obtained from representative material. In this case fire retardant treated southern pine plywood is intended to be used. Pre-existing cone calorimeter data is available on the United States Department of Agriculture (USDA), Forest Products Laboratory (FPL) Website[1] for various wood products and species including fire-retardant treated southern pine.

The USDA FPL website has data for fire-retardant treated southern pine for heat flux exposures at 20, 35, 50 and 65 kW/m². The data is summarized in Table 2 below.

Table 2 Cone calorimeter data

Test No.	Exposure Heat Flux (kW/m²)	Time to Ignition (s)	Effective Heat of Combustion (MJ/kg)
1a	20	1000.43	4.50
1b	20	923.58	5.02
2a	35	361.71	5.70
2b	35	476.89	5.98
3a	50	66.22	7.62
3b	50	58.81	7.25
4a	65	53.24	7.33
4b	65	38.51	8.12

[1] http://www.fpl.fs.fed.us/products/products/cone/introduction.php

III.2.2 Ignition Temperature

Following the procedure outlined in Section 4.6.5.1 of this Guide:

1. Determine the average time to ignition for each heat flux exposure level.

   The time to ignition is averaged for each exposure heat flux as shown in Table 3 below:

   Table 3a Average time to ignition

Test No.	Exposure Heat Flux (kW/m²)	Time to Ignition (s)
1	20	962.01
2	35	419.30
3	50	62.52
4	65	45.88

2. Correlate the average time to ignition by plotting $\left(1/t_{ig}\right)^n$ against the exposure heat fluxes. The value of n is determined based on highest correlation coefficient (R^2) of a linear best fit line, where n is between 0.5 and 1. Where n is closer to 0.5 the material is considered to have thermally thick surface properties. Where n is closer to 1, the material is considered to have thermally thin surface properties.

   Table 3b Inverse time to ignition

Test No.	Exposure Heat Flux (kW/m²)	Time to Ignition (s)	Inverse Time to Ignition (s-1)
1	20	962.01	0.0010
2	35	419.30	0.0024
3	50	62.52	0.0160
4	65	45.88	0.0218

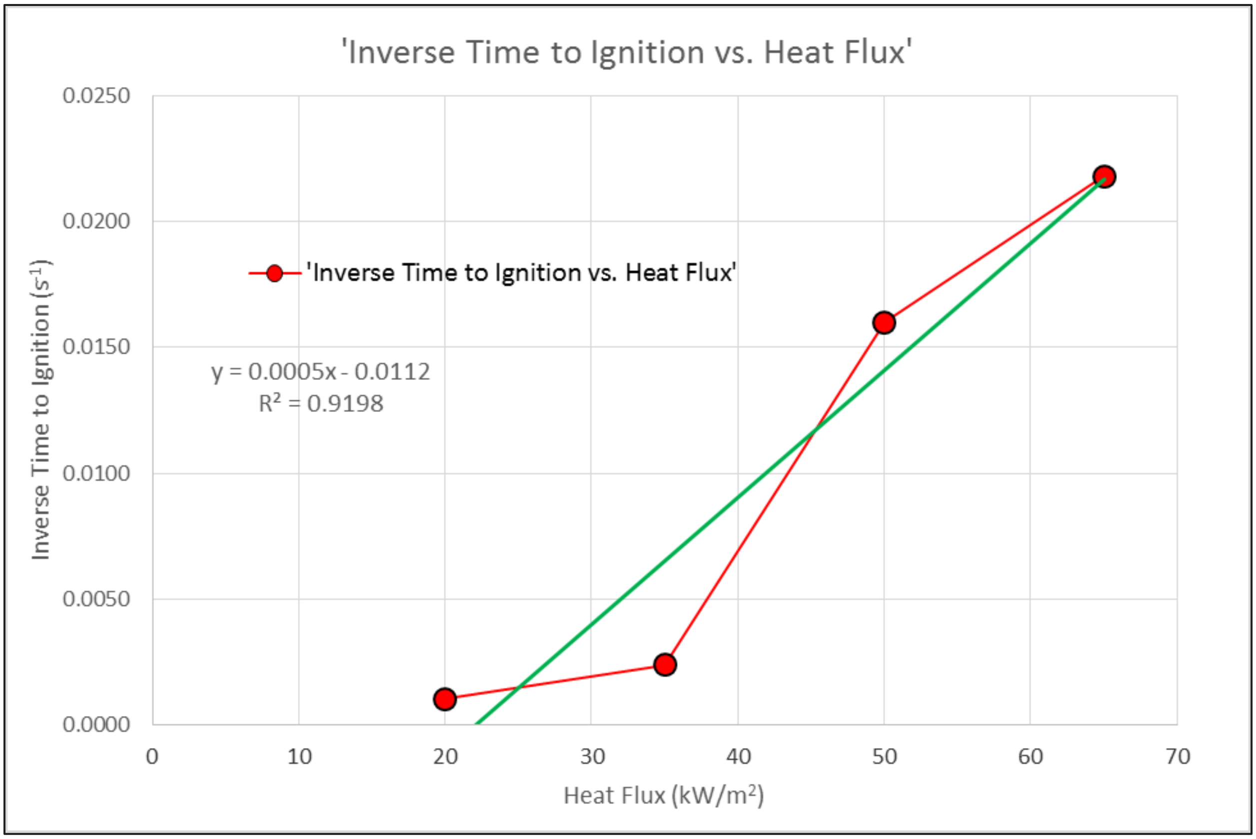

Figure 7 Plot of the inverse of time versus exposure heat flux

3. The theoretical critical heat flux for the material coincides with the point at which the line crosses the x-axis. The critical heat flux is the heat flux below which ignition under practical conditions cannot occur.

   The theoretical critical heat flux that is derived from this set of cone calorimeter data is 22.1 kW/m². This is a reasonable value. Several other samples included in the USDA FPL website for fire-retardant treated southern pine do not ignite at 20 kW/m² exposure.

4. The ignition temperature can be determined by solving the following equation:

   $$\varepsilon \cdot q''_{cr} = h_c\left(T_{ig} - T_\infty\right) + \varepsilon \cdot \sigma\left(T_{ig}^4 - T_\infty^4\right)$$

   Where:

   $\varepsilon = 1.0$

   $h_c = 10\ kW/m^2 \cdot K$

   $\sigma = 5.67 \times 10^{-11}\ kW/m^2 \cdot K^4$

   $T_\infty = 20\ ℃$

   Substituting these values into the equation above and solving the equation numerically by using the Newton-Raphson method results in an ignition temperature of 477°C.

III.2.3 Heat of Combustion and Thermal Properties

The heat of combustion is a function of exposure heat flux and selection of a representative value should be reflective of the expected exposure in the test being modelled. As noted in Section III.2.1 of this Guide, the expected exposure for the test is 45 kW/m² at 0.5 m above the opening and 27 kW/m² at 1.5 m above the opening and expected to lessen with height. A reasonable heat flux, representative of these values is 35 kW/m², which is the value used to establish a representative heat of combustion. The average heat of combustion from the 35 kW/m² cone calorimeter results for the fire-retardant treated southern pine is 5.84 MJ/kg.

Thermal properties such as heat of conduction, heat capacity and density are not readily available from cone calorimeter testing. These values can be obtained from literature. For this case, heat of conduction, heat of convection and density have been obtained from a paper by Kashiwagi on the "Effects of External Radiant Flux and Ambient Oxygen Concentration on Nonflaming Gasification Rates and Evolved Products of White Pine". The values are summarized in Table 4 below.

Table 4 Thermal properties

Property	Value
Heat of Conduction (W/m)	0.38
Heat Capacity (kJ/kg·K)	1.15
Density (kg/m³)	380

The thermal properties allow for the calculation of heat flow through the material, which can be used to establish temperature on the unexposed side of the material for purposes of predicting potential for ignition of interior wall components.

III.2.4 Heat Release Rate

As noted in the previous Section 4.2 of this guide, the representative exposure heat flux is 35 kW/m² for the CAN/ULC-S134 test. The heat release rate for the fire-retardant treated southern pine at an exposure heat flux of 35 kW/m² is shown in Figure 8 below.

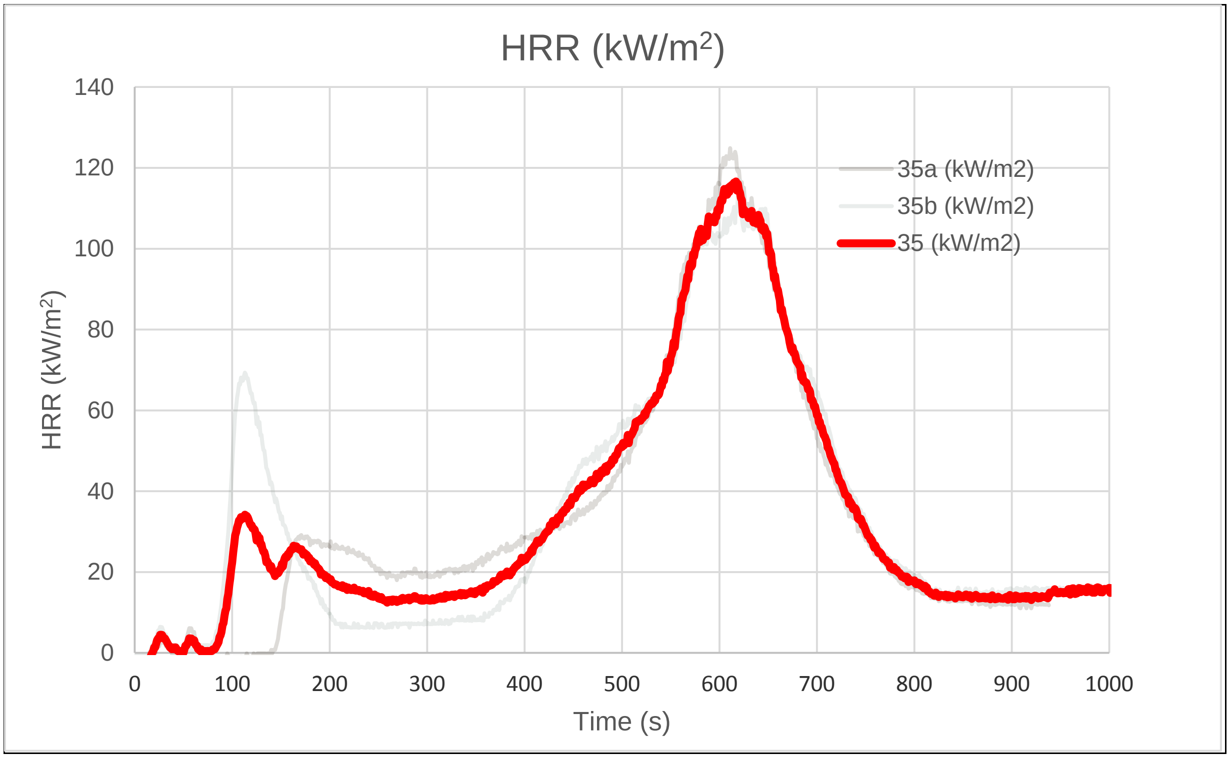

Figure 8 Plot of the heat release rate of the fire-retardant treated southern pine at an exposure of 35 kW/m²

III.3 Model Selection

As outlined in Section 4.4 of this Guide, model selection is based on choosing the model that is most appropriate for the intended purpose. In this case, the phenomena of interest are combustibility, flame spread, heat flux and flame height. Prediction of these phenomena requires complex underlying physics sensitive to heat transfer, velocity and chemical reactions on small time and geometrical scales. This degree of fidelity and complexity can often only be predicted using field/computational fluid dynamics (CFD) models.

The computational modelling used for this example is Fire Dynamics Simulator (FDS) version 6. FDS is developed by the Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST). FDS is an internationally recognized software package that represents the fire industry standard for fire CFD analysis. Model information, verification and validation is available from the NIST website[2].

FDS numerically solves a form of the Navier-Stokes equations appropriate for low-speed (< 0.3 mach), thermally-driven flow with an emphasis on smoke and heat transport. The governing equations for the conservation of mass, momentum and energy are discretized and solved across a rectilinear grid. A stoichiometric mixture fraction combustion model is used to determine combustion by-products (e.g. soot and CO). Turbulence is treated with Large Eddy Simulation (LES) with a variety of available

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[2] FDS-SMV Official Website, <http://www.fire.nist.gov/fds/verification_validation.html>

models for turbulent viscosity (the Deardorff model is the default methodology). The physical methods represented in the FDS sub-models are sufficient to represent the phenomena of interest for this case, provided the appropriate use of the model can be validated as discussed in more detail in the following section of this Guide.

III.4 Model Validation

Model validation is detailed in Section 4.7 of this Guide. Specific to the modelling of the CAN/ULC-S134 test, modelling the test calibration involves a sensitivity analysis relative to the heat release rate of the fire in order to cover the variation in the range of heat flux exposures to the exterior wall that may be impacted by shortcomings in the radiant heat transfer sub-model.

In addition to the sensitivity analysis, the Guide recommends mid-scale testing as a means of validating the material characteristics derived from the small scale testing (cone calorimeter in this case). Mid-scale testing is very much material specific and very little small- and mid-scale test data is available for a specific material. In this case, data is available for the small scale testing of southern pine. However, mid-scale data is not available for the same material. If mid-scale test data was available, the process described in Section 4.7.1 could be used to validate the appropriateness of the small scale test data.

Therefore, for purposes of this example, it is assumed that the material properties derived from the small scale testing are appropriate for use in the larger scale model, which is described in more detail in the following section of this report.

III.5 Full Scale Model

The material properties derived from the cone calorimeter tests described in Section III.2 of this Guide can be utilized in a model representative of the large scale CAN/ULC-S134 test described in the following sections of this Guide.

III.5.1 Model Geometry

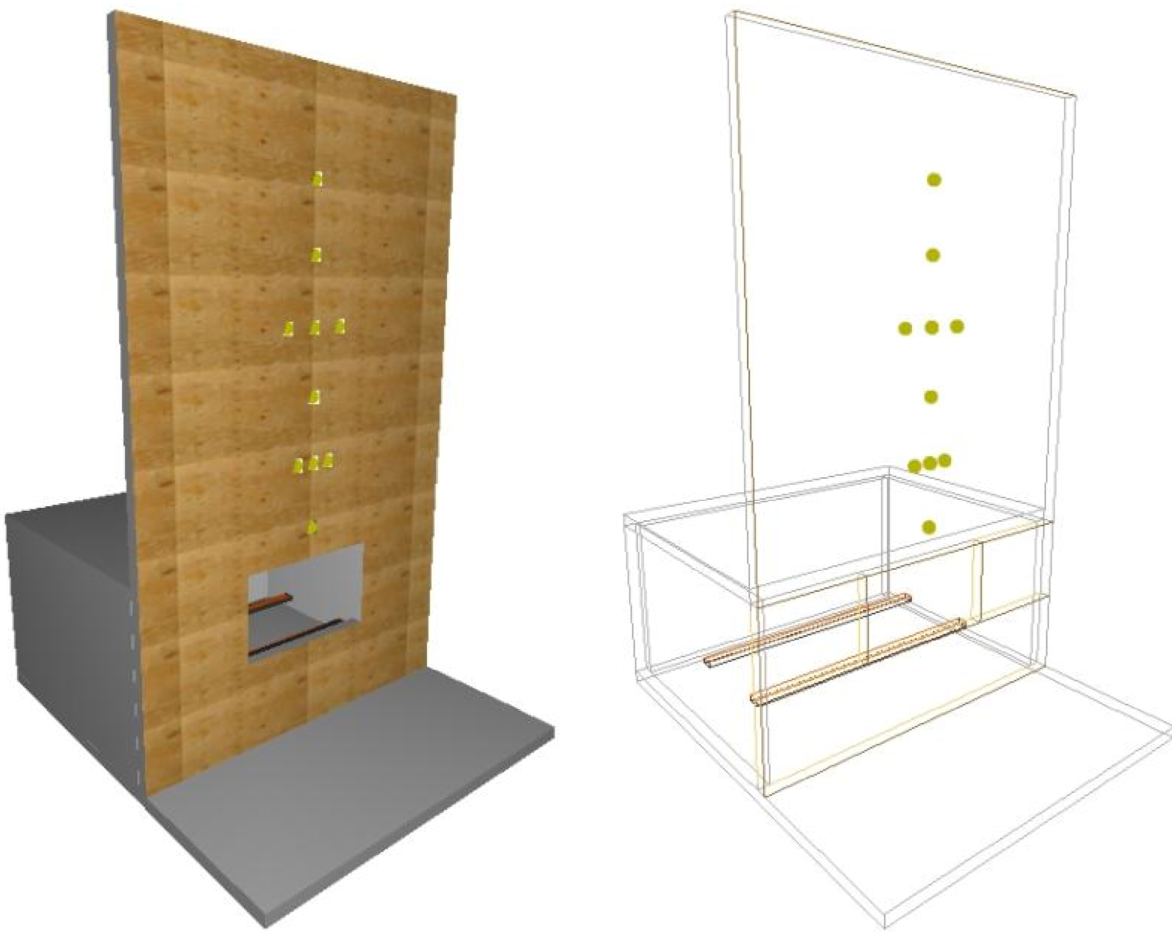
The model geometry for this example is defined in FDS using a combination of Obstructions (OBST) representing solid volumes and vents (VENT) representing active surfaces. Measuring devices are represented by virtual devices (DEVC) such as radiometers to measure heat flux and thermocouples to measure temperature. The obstructions, vents and devices are placed in a Cartesian coordinated system based on the measurements defined in the CAN/ULC-S134 test standard.

Obstructions make up the solid test apparatus construction based on defined material properties, as shown in Figure 9(a)**.** The material properties of interest in this example are:

- the fire-retardant treated southern pine surface with properties as defined in Section III.2 of this Guide, and
- inert test apparatus construction, which is primarily concrete blocks comprising the construction of the burn room.

The fire source is represented by two vents located within the burn room with a defined heat release rate established during the calibration phase. The fire sources are shown within the burn room in Figure 9(b).

The model geometry is discretized into cells having dimensions of 0.1 m by 0.1 m by 0.1 m for a total cell count of 432,000 cells.



(a) (b)

Figure 9 (a) model isometric view of the example exterior wall test apparatus, (b) transparent model isometric view of example exterior wall test apparatus.

III.5.2 Model Inputs and Parameters

The model input parameters, established as outlined in the previous sections of this guide, are summarized below.

Table 5 Model input parameters

Property	Value
Ignition Temperature (°C)	477
Heat of Conduction (W/m)	0.38
Heat Capacity (kJ/kg·K)	1.15
Density (kg/m³)	380
Peak Heat Release Rate (kW)	120

The heat release rate of the fire-retardant treated southern pine varies as a function of time, which can be defined as an input into the model. The heat release rate is defined as follows:

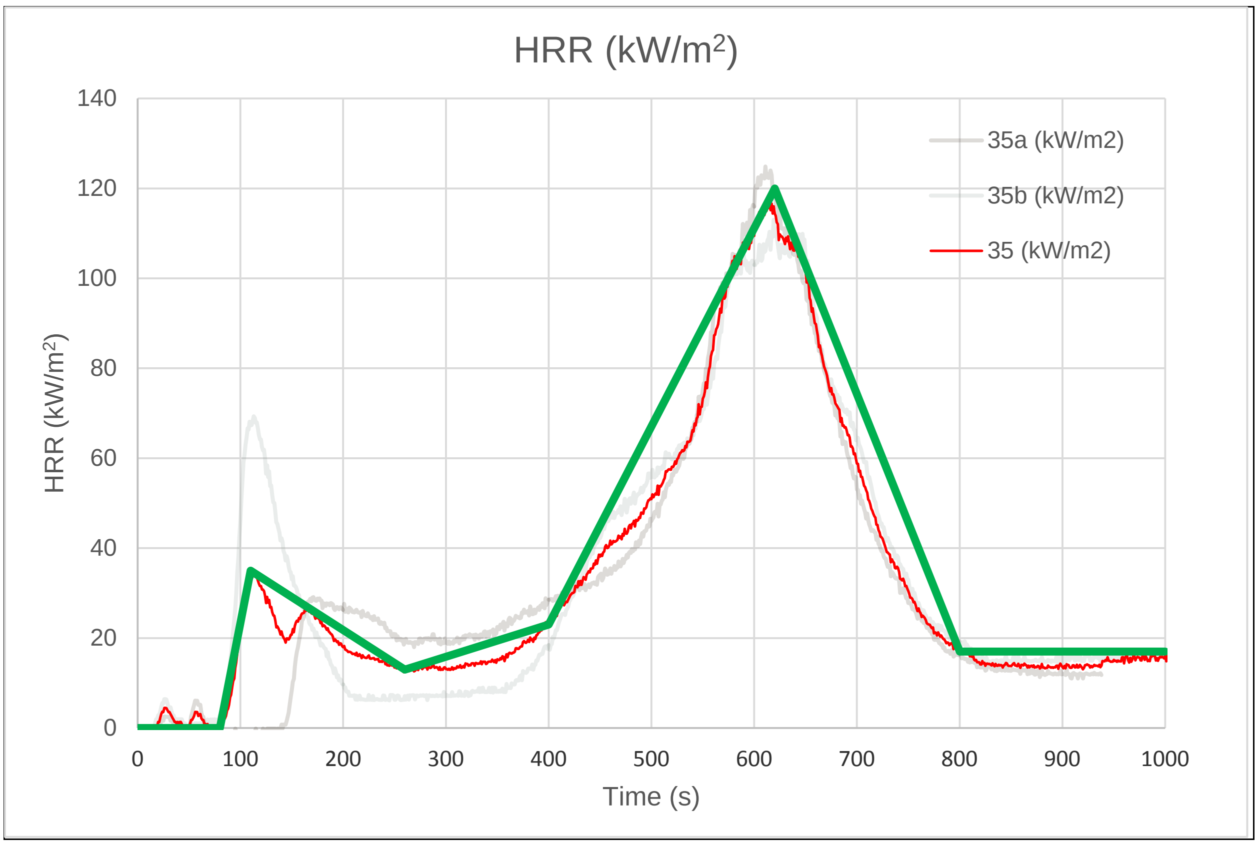


Figure 10 Plot of the heat release rate of the fire-retardant treated southern pine at an exposure of 35 kW/m², simplified for model input.

Table 6 Heat release growth

Time (s)	HRR (kW)	Fraction
0	0	0.00
80	0	0.00
110	35	0.29
260	13	0.11
400	23	0.19
620	120	1.00
800	17	0.14
1000	17	0.14

These properties are input into the model and the model run time is set for 1500 seconds. This is based on the CAN/ULC-S134 test run time having a fire source linear ramp up of 5 minutes, 15 minute steady-state phase and 5 minute ramp-down stage. These stages are well defined in Section 4.5.4 of this Guide.

III.5.3 Model Outputs

Model outputs should be defined to allow for confirmation of the key performance criteria. In this case, the key performance criteria is heat flux at 3.5 m above the burn room opening and flame height. These values can be measured using a radiometer device and flame isosurface defined in FDS. In addition to these, additional outputs are important to debugging the model and providing additional insight into performance. These include the following:

- Thermocouples on the sample surface at intervals above the burn room opening to measure temperature.
- Thermocouples on the unexposed side of the sample surface to establish heat transfer through the material to internal wall components.
- Radiometers at 1 m height intervals from the burn room opening to 5 m above the burn room opening to measure incremental incident heat flux on the sample surface.
- Surface incident heat flux to show 2D exposure.
- 2D temperature slices at height intervals of 1 m above the burn room opening and a 2D slice along the centre axis of the burn room opening.
- Temperature 3D isosurface to show fire temperatures near sample surface.

These outputs are shown in the model results included in the following section of this guide showing the model results.

III.6 Results

As outlined in Section 4.2 of this guide, the performance criteria used to assess the performance of a non-loadbearing infill wall assembly when tested in conformance with CAN/ULC-S134 is:

- Flaming on or in the wall assembly shall not spread more than 5 m above the opening during or following the test procedure.
- The heat flux during the flame exposure on a wall assembly shall be not more than 35 kW/m² measured 3.5 m above the opening during the test procedure.

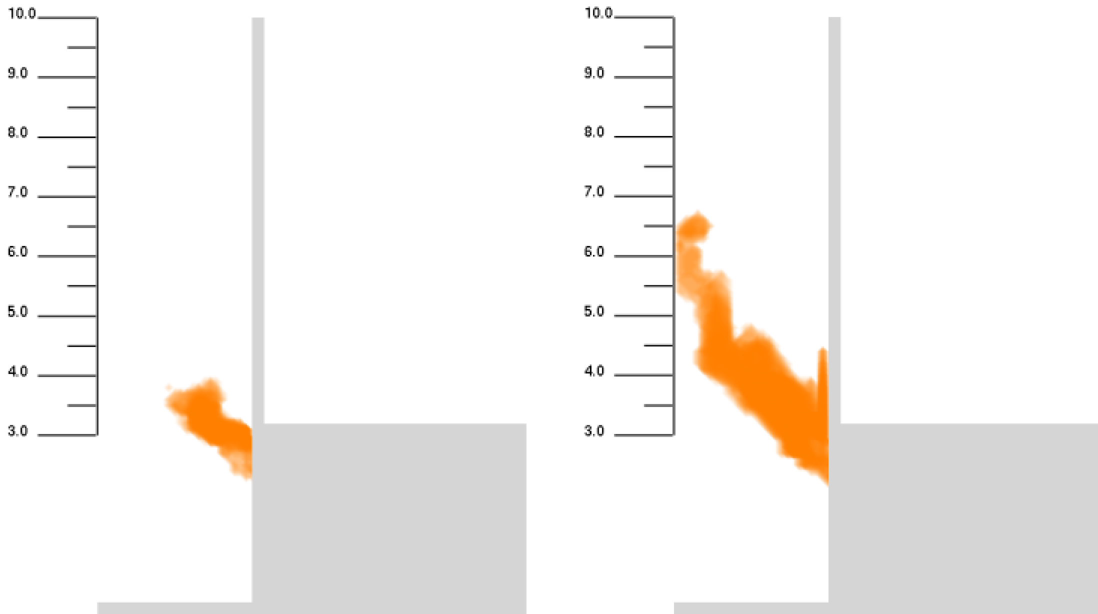
This criteria is used to examine the results of the modelling, which are summarized in the following sections of this guide.

III.6.1 Flame Height

The model can be used to predict the flame region as a function of gas diffusion and the combustion reaction. The flame height using the predicted flame sheet ranged between 1 m and 3.5 m above the opening during the peak burning period and 0 m to 1.5 m on the surface of the wall, as shown in Figure 11(a) and (b)**.** This result is within the limits of the performance criteria, which requires that “flaming on or in the wall assembly shall not spread more than 5 m above the opening”.

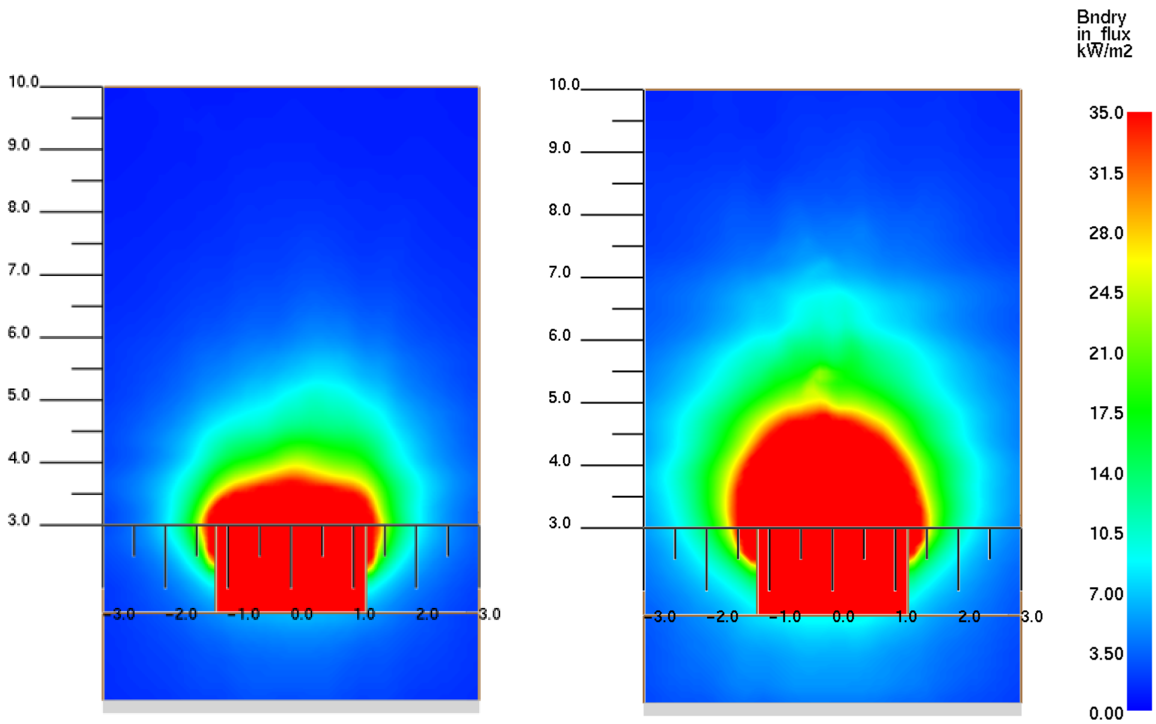
III.6.2 Heat Flux

The heat flux incident on the exterior surface of the wall as a result of flame spread and exposure from the flame is shown in Figure 12(a) and (b). The result is within the limit of the performance criteria, which requires that “The heat flux during the flame exposure on a wall assembly shall be not more than 35 kW/m² measured 3.5 m above the opening.” The maximum incident heat flux at 3.5 m above the opening was predicted by the model to be 9.25 kW/m².



(a) (b)

Figure 11 Side view of flame height at (a) 3 minutes and 40 seconds, (b) 13 minutes and 40 seconds.



(a) (b)

Figure 12 Front view of incident heat flux at (a) 5 minutes, (b) 13 minutes and 40 seconds.

III.6.3 Inner Wall Temperature

As shown in Figure 13, the model predicts that the exterior wall cladding material immediately above the opening progressively burns away through the test. The model assumption is that the exterior wall has no void spaces to spread fire. Therefore, the burning of the material is only predicted from the exterior surface.

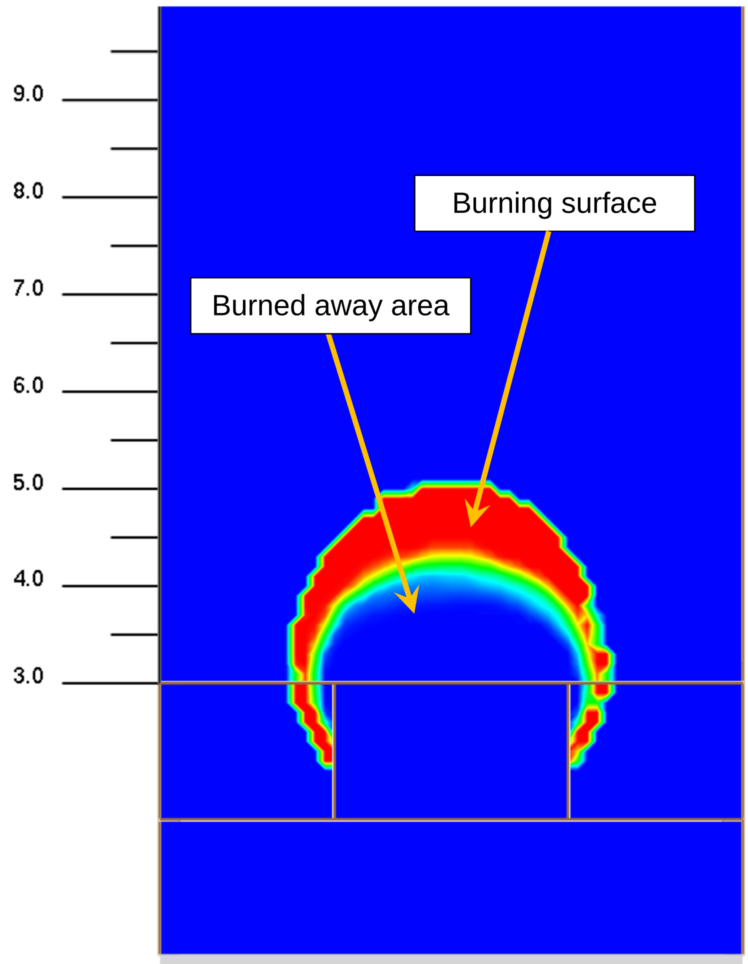
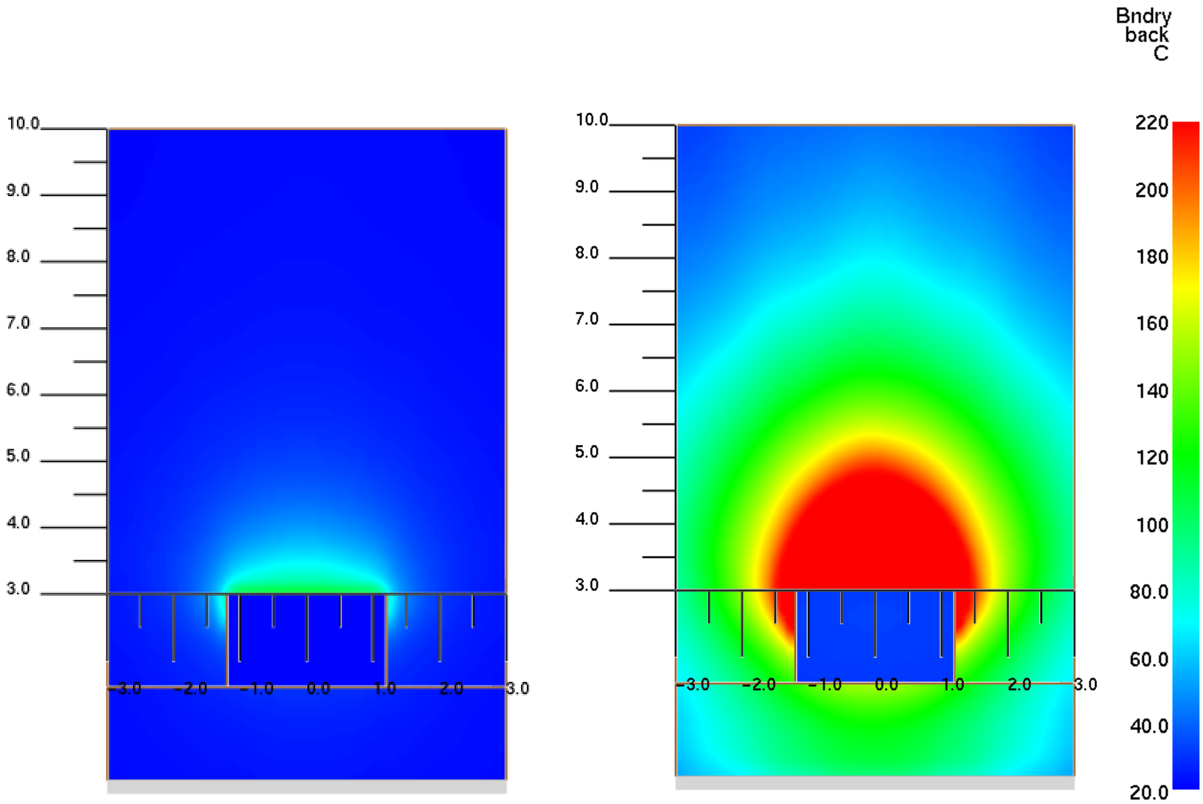


Figure 13 Front view of the model showing burn surface.

The inner wall temperature was also predicted by the model based on one dimensional heat transfer through the wall. As outlined above, the assumption of the model is that there are no void spaces behind the wall to spread fire. The purpose of estimating the temperature on the interior side of the exterior cladding was to examine the propensity for ignition to occur within the wall. The results of the interior wall temperature are shown in Figure 14 indicate that the inner wall temperature exceeds 220°C where burn-through of the exterior cladding occurs. Beyond this boundary, the predicted temperature is below the predicted ignition temperature of the fire-retardant treated surface material.



(a) (b)

Figure 14 Back wall temperature at (a) 5 minutes, (b) 21 minutes.

III.7 Summary

The example summarized above has been provided for illustrative purposes only, and is not intended to be used for design. Additional testing and model validation would be required to confirm that the results predicted by the model are appropriate. Assuming the results can be validated, the example illustrates that modelling can be used in lieu of full-scale testing as a predictive tool to support alternative methods of assessment.

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