Spatial separation: historical analysis and rationale

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Spatial Separation

Historical Analysis and Rationale

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1.0 EXECUTIVE SUMMARY

This report provides a historical analysis of the spatial separation requirements in the National Building Code of Canada (NBC), focusing on the development of Articles 3.2.3.1. and 3.2.3.2., Tables 3.2.3.1.-A to 3.2.3.1.-E in Part 3 and Articles 9.10.15.1. to 9.10.15.4., Tables 9.10.14.4.-A and 9.10.15.4. in Part 9 of Division B. The analysis is primarily focused on the 1958 St. Lawrence Burn Tests, particularly the fire tests conducted on Building Nos. 4 and 5, which established foundational data for radiant heat exposure and incident heat flux that formed the basis of these requirements.

The report documents the development of the spatial separation tables and associated requirements from the St. Lawrence Burn Tests to more recent changes associated with the concentration of openings and fire department arrival time. This includes a detailed discussion of the results of the St. Lawrence burn tests and the conversion of those results into the specific spatial separation requirements that exist in the current 2020 NBC, including the modifications that have occurred since.

Recommendations include reviewing the applicability of the flame front factor used in the development of the spatial separation table values, reconsidering the 10-minute fire department arrival time assumption, reassessing concentrated openings in the context of the enclosing rectangle approach used in the UK and New Zealand, and extending the method for calculating unprotected openings for staggered and skewed building faces from Part 9 to Part 3 buildings.

2.0 PURPOSE

The Construction Research Centre of the National Research Council (NRC) has developed the "Construction Sector Digitalization and Productivity Challenge program" to "support new solutions to increase innovation potential and productivity in the construction sector through the use of digital technology" [1]. This report has been prepared to review and document the historical changes, performance targets, calculation method(s) and assumptions for spatial separation and exposure protection provisions in the 2020 National Building Code of Canada (NBC), Parts 3 and 9 of Division B.

The information in this report is drawn from a case study that is part of an, as yet, unpublished thesis [2], which is currently under revision. This report has been independently reviewed by peers and is also subject to NRC's technical review process.

3.0 INTRODUCTION

Currently, the NBC acceptable solution requirements to limit fire spread from one building to an adjacent building are prescriptive and were developed based primarily on fire experiments conducted in the late 1950s. However, these requirements have evolved and expanded to include the impact of other design features and requirements, such as the type of material on the exposed building face, fire department response times, and projections.

This report details an analysis of current provisions and reviews historical changes and related documentation to clarify the current performance targets, calculations, and evaluation methods; all within the limitation of the available literature related to the NBC provisions on spatial separation and exposure protection. Specifically, the scope of this report is as follows:

1) Review and document the historical changes for spatial separation provisions in the NBC, specifically Articles 3.2.3.1. and 3.2.3.2. in Part 3 and Articles 9.10.15.1. to 9.10.15.4. in Part 9 of Division B. This includes identification of current performance targets.
2) Describe calculation methods and assumptions used to develop Tables 3.2.3.1.-A to 3.2.3.1.-E, 9.10.14.4.-A, and 9.10.15.4. starting with the original St. Lawrence Burns.
3) Identify research gaps and provide recommendations for future analyses.

The following sections of this report detail the elements of the St. Lawrence Burn Tests related to the spatial separation requirements and associated development of the spatial separation table values, requirements associated with concentration of openings, fire department arrival time, and equivalent opening area. The information in this report is drawn from a case study included in an as yet unpublished thesis [2], which is currently under revision.

4.0 ST. LAWRENCE BURN TESTS

In the development of the St. Lawrence Power Project, a large area on the Canadian side of the St. Lawrence river was flooded [3]. This area included several villages with lands expropriated by the Ontario Hydro Electric Power Commission. Prior to flooding, the Fire Section of the Division of Building Research of the National Research Council conducted burn tests in eight full-scale buildings in the village of Aultsville in 1958, located on the north bank of the St. Lawrence river [4].

The fire tests were conducted in January and February of 1958 in six two storey houses and two larger structures (a school and community hall) [4]. Members of the Joint Fire Research Organization (JFRO) of the UK participated in the testing and analysis of the results [5].

4.1 Test Objectives

The objective of the St. Lawrence burn tests was to examine the development of fire within buildings with a particular focus on [4]:

1. occupant survivability,
2. ventilation rates, and
3. spread of fire by radiant heat.

The following phenomena related to the spread of fire by radiant heat were examined [4]:

- Radiation intensity at a distance.
- Radiant temperature at the openings of a burning building.
- The flame front distance from the openings in a building face.

With respect to these phenomena, the spatial separation regulations of the NBC were almost exclusively based on the results of the fire tests conducted in Building Nos. 4 and 5.

4.2 Test Setup

The following sections detail the building layouts, construction materials, openings, fuel load and radiometer setup for Building Nos. 4 and 5.

4.2.1 BUILDING LAYOUT

Building Nos. 4 and 5 were both residential buildings (**Figure 4-1** and **Figure 4-3** respectively), two storeys in building height, with similar building areas. The test layouts for Building Nos. 4 and 5 are shown in **Figure 4-2** and **Figure 4-4** respectively. Each layout shows the ground floor on the left and the "first" floor (second storey) on the right. The walls are highlighted in grey, the window openings are highlighted in blue, and the exterior doors are highlighted in green.

Figure 4-1: Building 4.

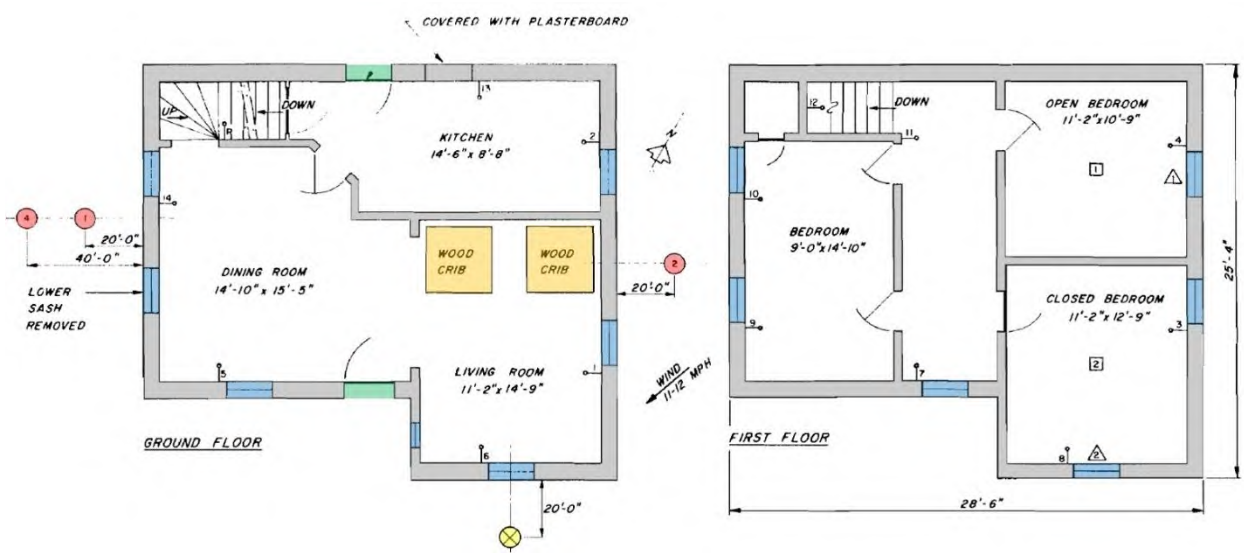

Figure 4-2: Burn 4 layout.

Figure 4-3: Building 5.

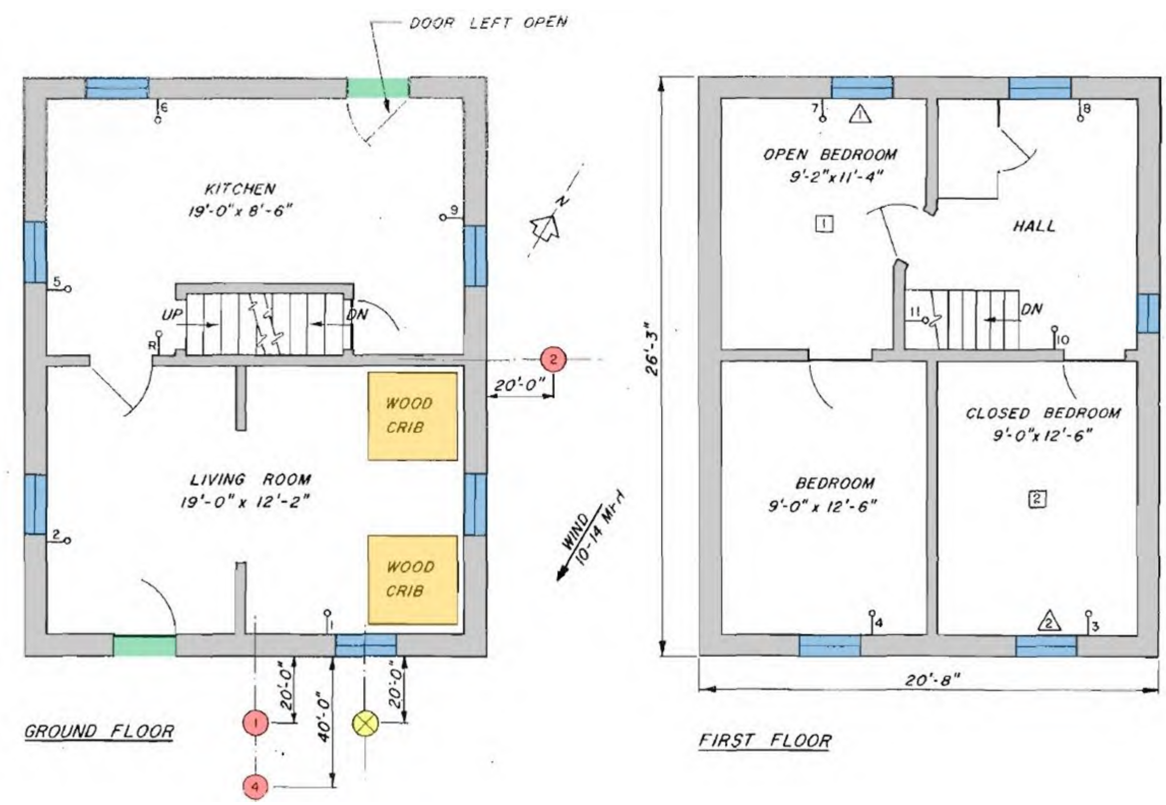

Figure 4-4: Burn 5 layout.

4.2.2 OPENINGS

All windows and exterior doors in Building No. 4 were in a closed position at the start of the test. The back exterior door on the ground floor of Building No. 5 was left in the open position at the start of the test. All other windows and exterior doors of Building No. 5 were reported to be in a closed position.

4.2.3 FIRE LOAD

Building Nos. 4 and 5 included a combustible fire load that was concentrated to the living room of the buildings, highlighted orange in **Figure 4-2** and **Figure 4-4** respectively. The fire load was intended to represent average residential fire loading based on Ingberg's survey [6], and consisted of two hemlock based wood cribs with a density of 464.5 kg/m² (29 lb./ft³) for a combined weight of 303.9 kg (670 lbs). A photograph of one of the cribs is shown in **Figure 4-5**. The fire load for Building Nos. 4 and 5 is detailed in **Table 4-1** and compared to the loading from Ingberg's survey.

Figure 4-5: Fire load – wood cribs.

Table 4-1: Fire load.

Burn No.	Net Floor Area, Room of Origin (m² [ft²])	Wood Crib Fire Load (kg/m² [lb/ft²])	Average Survey Fire Load (kg/m² [lb/ft²])
4	Dining room – 19.4 [209] Living room – 15.3 [165] Total – 34.7 [374]	8.8 [1.8]	17.1 [3.5]
5	Living room – 21.1 [227]	14.6 [3.0]	19.0 [3.9]

In addition to combustible contents, Ingberg's survey also included combustible lining materials and flooring. However, the fuel load of the combustible interior finish in Building No. 5 was not quantified, nor was the combustibility of the floor material identified or quantified as part of the reported fire load in either building.

The wood cribs also included crumpled paper in the base, which was ignited using another rolled-up paper. The timer for each test was not started until it was confirmed that ignition of the cribs had occurred and fire was established [4].

4.2.4 RADIOMETERS

Radiometers were developed [7], provided for the burn tests and operated by the British Joint Fire Research Organization (JFRO) [4, 8]. They were custom made for the St. Lawrence tests [8]. An example is shown in **Figure 4-6**. The radiometers consisted of two gold receiving discs within a heavy brass body to limit the rate of rise of temperature of the body relative to the gold discs [8]. The primary blackened gold disc was located behind a thin mica cover and had a thermocouple attached. A second gold disk was mounted within the sensor body as a cold junction. Given the custom nature of the radiometers and short supply timeline, their sensitivity to wind was not examined prior to the tests [8].

The radiometers for Building Nos. 4 and 5 are shown highlighted red in **Figure 4-2** and **Figure 4-4** respectively. They were located at the centre of each wall they faced, and were mounted to stands at 3.0 m [10 feet] in height for those located 12.1 m [40 feet] from the test building face, and at 4.6 m [15 feet] in height for those located 6.1 m [20 feet] from the test building face.

Thermopile radiometers were also provided [9, p. 5] "to measure the equivalent black body temperature of a window where the fire started," highlighted yellow (circle with an X in the centre) in **Figure 4-2** and **Figure 4-4**.

Figure 4-6: Radiometer.

4.2.5 THERMOCOUPLES

Thermocouples to measure temperature were installed in Building Nos. 4 and 5 as shown by the combined circle and lines (o--), located adjacent to walls in **Figure 4-2** and **Figure 4-4** respectively. Each thermocouple was located 1.2 m [4 feet] above the floor and 0.20 m [8 inches] from the wall [4]. The thermocouples at the foot of each stair were located at ceiling level.

4.3 Test Results

Fire tests were conducted in Building Nos. 4 and 5 on January 15 and 16 respectively, in 1958. The radiant heat was measured as discussed in **Section 4.2.4**, in conjunction with other measurements and observations [4, 8-15]. The tests were filmed by the National Film Board of Canada; visual observations were made by staff of the Fire Section of the Division of Building Research of NRC; and instrumentation was incorporated in the test buildings to measure temperature, smoke, gas concentration, ventilation rate and sound. The results of the tests have been documented in reports that include plots of the data, but not the original data. A software tool, WebPlotDigitizer [16] was used to extract data from the plots.

4.3.1 General Results and Observations

The environmental conditions were recorded and are detailed in **Table 4-2**. For Building No. 5, it was noted that [4, p. 24] “the weather had deteriorated badly,” resulting in frequent wind gusts as the test progressed.

Table 4-2: Environmental conditions during testing.

Burn No.	Temperature (°C [°F])	Relative Humidity (%)	Wind	
			Direction	Speed (kph [mph])
4	-6.7 [20]	60	NE	17.7-19.3 [11-12]
5	-7.8 [18]	95	N	16.1-22.5 [10-14] (frequent gusts)

The fire developed rapidly in Building No. 5 and spread to involve the entire structure within a short period of time in comparison to the fire in Building No. 4. For context, a side-by-side comparison showing exterior fire extension from each building is shown at 11 minutes in **Figure 4-7** and at almost 16 minutes in **Figure 4-8**.

(a) (b)

Figure 4-7: 11 minutes, (a) Building No. 4, (b) Building No. 5.

(a) (b)

Figure 4-8: 15 minutes, 49 seconds, (a) Building No. 4, (b) Building No. 5.

Key observations made by NRC Fire Section staff are detailed in **Table 4-3** [4]. Several additional observations were noted as follows [15]:

- Buildings lined with combustible material in the testing had radiation levels twice as high as those with noncombustible linings.
- If I represents the radiation intensity at a distance from a building and F is the configuration factor of the openings at the measurement point, then the ratio I/F provides a convenient means to compare radiation levels across different buildings.
- During peak radiation periods, the radiant heat directly emitted from openings in the exterior walls was significantly lower than that emitted from the flames above and around the windows.
- Peak radiation levels were recorded after approximately 16 minutes.
- Wind had an impact on the radiant heat levels, but the results were insufficient to quantify the effects. Recorded wind speeds ranging from 16.1-22.5 kph [10 to 14 mph] could have significantly impacted the burning rate.
- Combustible exterior siding did not appreciably increase the maximum radiation levels from a house.

Table 4-3: Key visual observations.

Key Observation	Time (min:sec)	
	Burn No. 4	Burn No. 5
Flame coming out of front living room window	11:00	08:00
Exterior cladding ignited	13:00	08:25
Ceiling temperature at foot of stairs (900 °F)	11:00	02:30
Front wall completely involved in fire	31:30	14:00
Flame front extension (The flame front for Building No. 5 at approximately 11 minutes is shown in **Figure 4-9**.)	32:00 (3.0 [10 ft])	09:15 (1.2 [4 ft]) 11:00 (2.1 [7 ft]) 12:00 (3.0 [10 ft]) 15:00 (4.6 [15 ft])

Figure 4-9: Building No. 5 flame front at approximately 11 minutes.

4.3.2 Room Temperatures

The thermocouples used to measure the temperature within the test buildings were strategically located as well as distributed throughout the ground floor, as shown in **Figure 4-2** and **Figure 4-4**. The temperature results for the thermocouple above the wood cribs, at the foot of the stairs (to the upper floor), and throughput the ground floor level are shown in **Figure 4-10**. Building No. 5 temperature results are shown in red and Building No. 4 temperature results are shown in blue. The solid lines show the temperature above the wood cribs, which is similar for both tests. The dashed lines show the temperature at ceiling level at the foot of the stairs to the upper level.

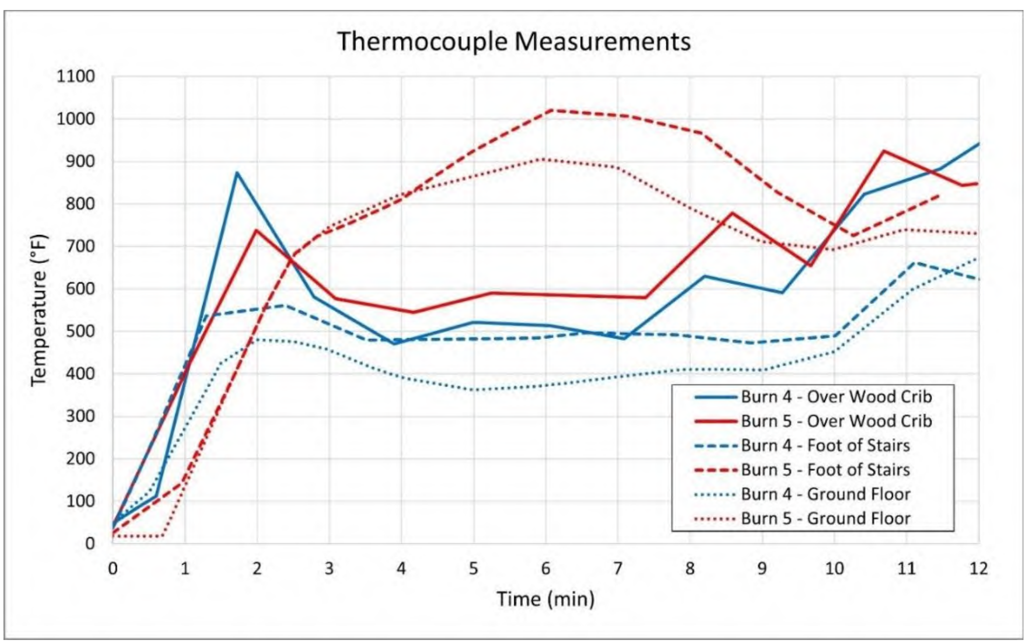

Figure 4-10: Plot of room temperatures.

The stair temperature for Building No 5 is similar to Building No. 4 between 1 to 2 minutes, and then increases to approximately 538 °C (1000 °F) at 6 minutes, which is twice as much as for Building No. 4. The result is similar for the temperature in the general floor area (i.e., Building No. 5 result is approximately twice that of Building No. 4), but lower than the temperature above the foot of the stair. This outcome is expected, given the general floor area result is an average of all the thermocouples on the ground floor.

4.3.3 RADIANT TEMPERATURE OF OPENINGS

The results of the thermopile radiometers were processed to establish the radiant temperature of window openings during the tests. It was found that the temperatures ranged between approximately 200 °C and 1000 °C as a function of the degree of fire development of fire at the window opening measured, and the degree of smoke obscuration. The radiant temperature of window openings of buildings with combustible interior finish reached higher values sooner than for buildings with noncombustible interior finish [9]. The radiant temperature for Building No. 5 was generally lower in comparison to other tests of buildings with combustible interior finish [9]. This was a result of smoke obscuration at the Building No. 5 openings during the test.

The calculated radiant temperature reached up to 1003 °C in one test (Building No. 2) for a brief period of time, but remained below 1000 °C for the remainder of the Building No. 2 test and the other tests [9]. Based on these results, the conclusion of the measurements and calculations of radiant temperature of openings supports the assumption that windows of a compartment completely involved in fire radiate heat as a black body at 1000 °C [9].

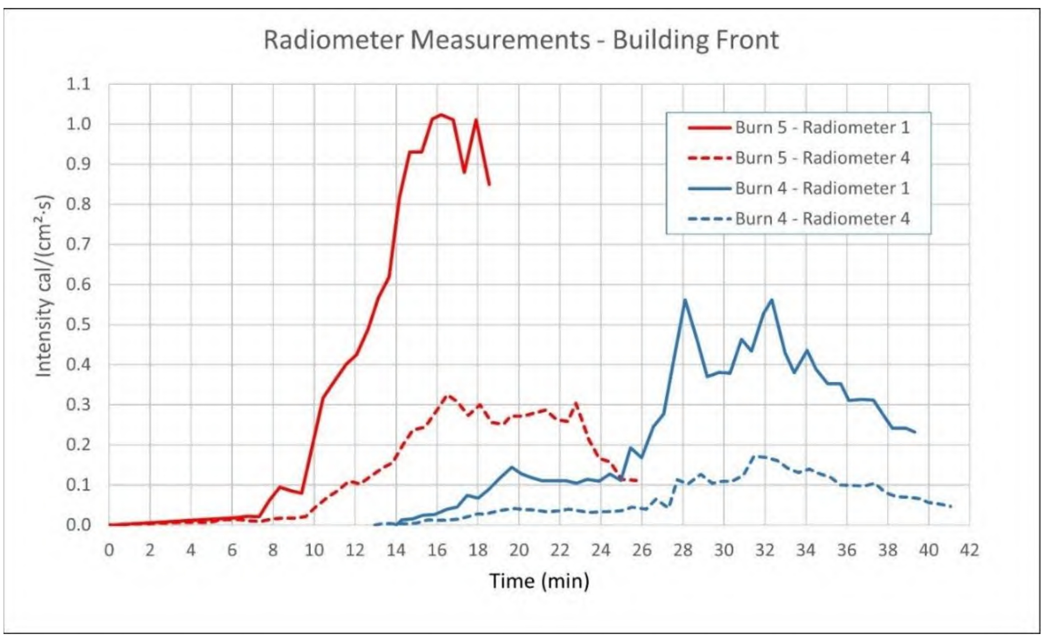

Figure 4-11: Plot of heat flux at radiometers.

4.3.4 INCIDENT HEAT FLUX

The radiometers were located 6.1 m [20 feet] and 12.1 m [40 feet] respectively from the front of each building, as shown in **Figure 4-2** and **Figure 4-4**. The results from these radiometers for Building Nos. 4 and 5 are shown in **Figure 4-11**. The Building No. 5 radiometer results are shown in red, and the Building No. 4 radiometer results are shown in blue. The solid lines show the radiometer results at 6.1 m [20 feet], and the dashed lines show the radiometer results at 12.1 m [40 feet] from the front of each building respectively. The results from the radiometers located 12.1 m [40 feet] from the front of each building are lower than those located 12.1 m [20 feet] from the front of each building, given radiant intensity decreases with the square of the distance from the fire. The relationship between the 6.1 m [20 feet] and 12.1 m [40 feet] radiometer readings will be discussed in more detail in **Section 5.2**, relative to their configuration to the openings in the face of each test building (configuration factor) and the normalization of the readings.

The radiometer results for Building No. 4 are approximately half those for Building No. 5, and have delayed growth and peak phases compared to the results of Building No. 5.

5.0 SPATIAL SEPARATION TABLE DEVELOPMENT

As noted in **Section 4.0**, the results of the tests in Building Nos. 4 and 5 of the St. Lawrence burns were used in the development of the spatial separation regulations in the NBC. The use of these results was intended to provide a more technical basis than had been utilized in the development of the building separation requirements in the 1953 NBC. The results of the tests in Building Nos. 4 and 5 were quite complex and required abridgement to be expressed in a regulatory format such that they could be applied broadly to building design and construction. The following sections describe the assumptions, simplifications and analyses used in converting the test results to regulations.

5.1 Radiant Heat Exposure Equation

The general approach used in the development of the spatial separation regulations was the analysis of the test data to establish:

1. the radiant emissive power of the fire (the hazard),
2. a simplified means to analyze the relationship between the radiant emissive power and the incident heat flux at a distance from a burning building (relationship),
3. the incident radiant heat exposure below which a building is not likely to ignite (the exposed and acceptable performance).

The following sections detail the approach to abridge the test data into a regulation-based format, which required several key assumptions and simplifications.

5.2 Radiometer Configuration Factor and Source Radiant Emissive Power

Characterization of the exposure hazard required an understanding of the radiant emissive power from the openings in the face of each of the test burns. This could be determined based on the black body temperature of the openings (**Section 4.3.3**), assuming the openings are the only emitting source. However, this approach was not considered representative of the exposure hazard due to the degree of flame extension observed during the tests.

The exposure hazard could be more accurately characterized from the radiometer measurements detailed in **Section 4.3.4**. However, since these measurements represented the incident heat flux at the point of measurement (i.e., 6.1 m [20 feet] and 12.1 m [40 feet] respectively from the front of each test building), they required normalization back to the building face to establish the source emissive power. Normalization required an understanding of the geometrical relationship between the fire and the radiometer sensors, which was challenging due to the varying flame area and extension over time as illustrated for Building No. 5 in **Figure 4-8(b)** and **Figure 4-9**. This was addressed by assuming the measured heat flux originated only from the openings in the face of each building (i.e., windows and doors), which allowed a simpler geometrical representation of the fire (emitting source). However, this also resulted in an artificially high radiant emissive power from each opening and corresponding black body temperature, deviating from the 1,000 °C identified in **Sections 4.2.4** and **4.3.3**. This assumption has caused some confusion and the attribution of unrealistic peak temperatures to building fires. In particular, at least one regulatory guide [17] referenced a peak temperature of 1311 °C in the St. Lawrence burn tests. This temperature reference has since been removed following a “Public Input” describing the origin of the artificially high radiant emissive power values and the underlying assumption (simplification) [18].

The assumption that the radiant emissive power originates from the openings alone then allowed for a straight-forward geometrical (configuration factor) analysis to establish the emissive power from the openings in the face of each building as a function of the radiometer measurements. The configuration factor represents the fraction of heat from a source (fire) to a point, as a function of the distance and configuration. Therefore, knowing the heat flux received at a point and its associated configuration factor to the source, allows for an approximation of the source emissive power.

These configuration factors from the openings in each building face to the radiometers have been provided in reports summarizing the results of the tests, and are included in **Table 5-1** [15, 19].

Table 5-1: Calculated configuration factors for Building Nos. 4 and 5.

Building No.	Radiometer No.	Configuration Factor
4	1 (20 ft)	0.032
	4 (40 ft)	0.011
5	1 (20 ft)	0.027
	4 (40 ft)	0.008

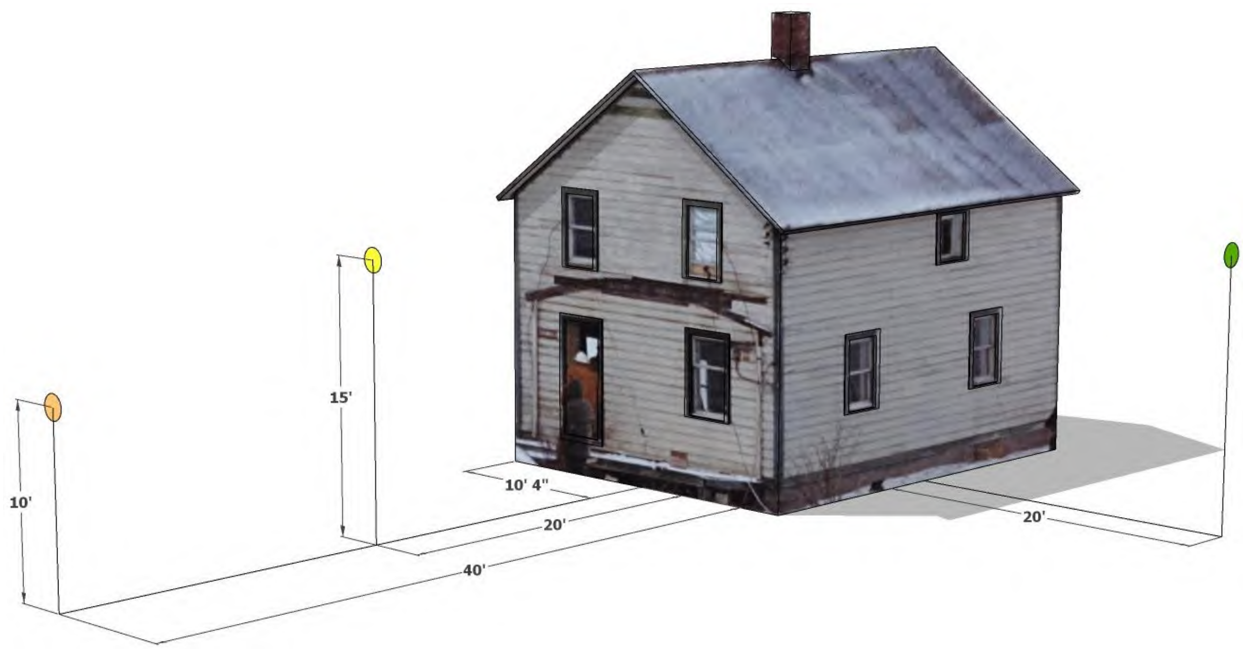

Figure 5-1: SketchUp 2023 model of Building No. 5.

The configuration factors for Building No. 5 were confirmed based on scaled measurements from the test setup layouts, shown in **Figure 4-4**, as well as photogrammetry using a tool in SketchUp 2023 [20]. The SketchUp model of Building No. 5 is shown in **Figure 5-1**. Radiometers 1 and 4 are shown in yellow and orange respectively and radiometer 2 is shown in green. The same exercise was not undertaken for Building No. 4, but is assumed to be similarly valid.

Based on the respective configuration factors in **Table 5-1**, the radiometer readings were recalculated to determine the radiant emissive power of the building openings using **Equation 5-1**. The recalculated radiometer measurements, representing the radiant emissive power of the openings in test Building Nos. 4 and 5, are shown in **Figure 5-2**.

$$E = \frac{I_r}{\phi_o}$$ **Equation 5-1**

Where:

E	=	Emissive power of the openings (cal/cm²·s)
I_r	=	Radiometer measurement (cal/cm²·s)
ϕ_o	=	Configuration factor of the openings to the radiometer

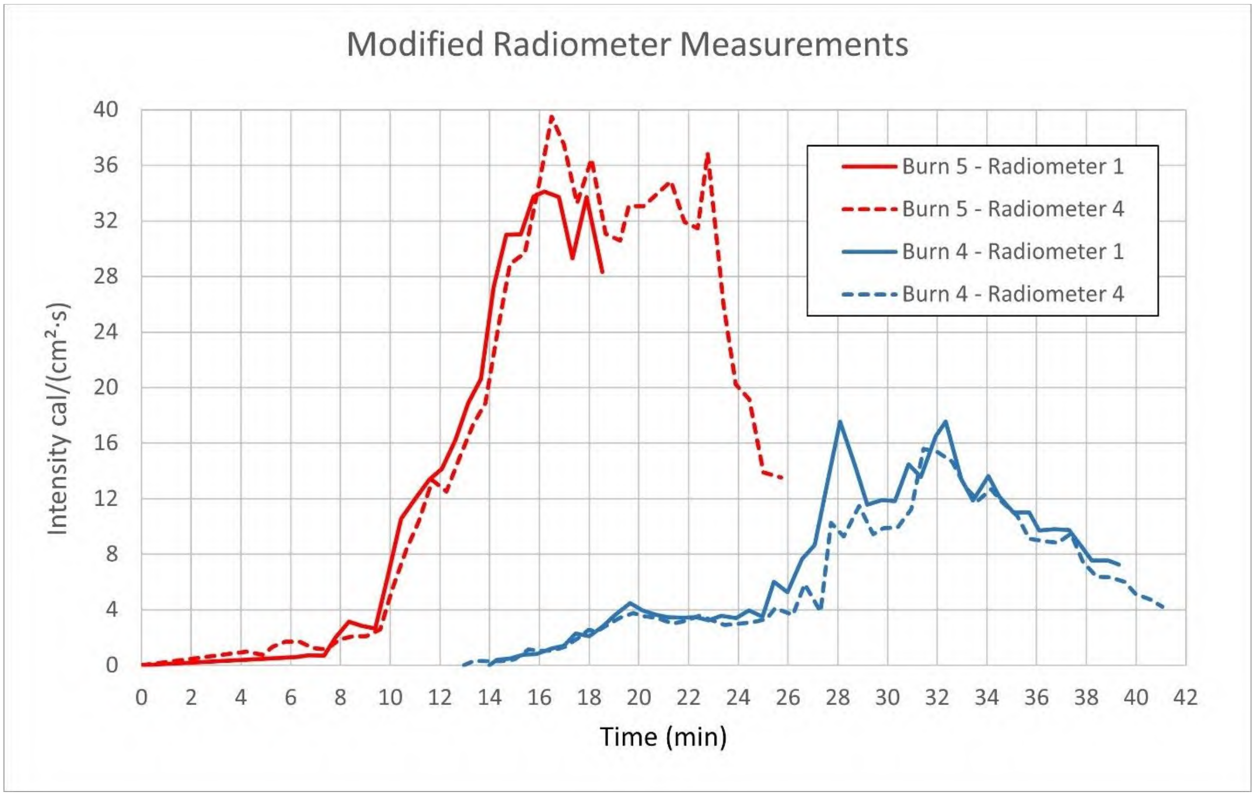

Figure 5-2: Plot of the radiant emissive power of the openings.

Radiometers 1 and 4 measured the incident radiant heat flux from the same face of each respective building; therefore, once the configuration factor of each radiometer is known and applied to the results, there is general agreement between radiometer devices as shown in **Figure 5-2**. Using this method to calculate the source emissive power, the next step in regulatory development was to identify the resulting degree of exposure that adequately characterized the hazard with respect to 'safe' distances between buildings. Initially, the peak measurements were used. However, this resulted in impractical distances. This was addressed through another significant assumption, that a fire department is expected to arrive and control an exposure fire within 10 to 11 minutes. Applied to the results of the Building No. 5 fire, this assumption resulted in a reduced source radiant emissive power of 8.5 cal/cm²·s (356 kW/m²). This is shown in **Figure 5-3** by the intersection of the dark red line with the 10- and 11-minute times and the corresponding intersection on the radiant intensity axis. The average of this intersection is shown by the dark blue line at 8.5 cal/cm²·s (356 kW/m²).

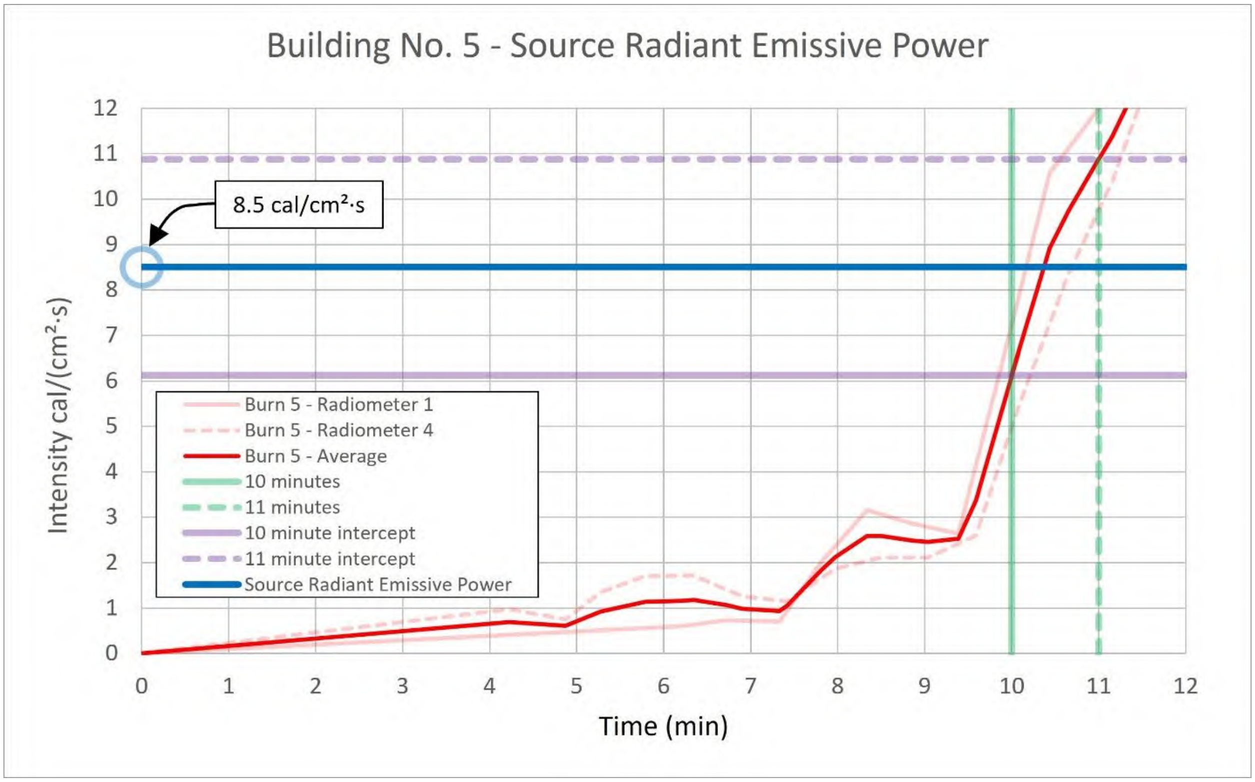

Figure 5-3: Building No. 5 radiant emissive power of the openings at 10 to 11 minutes.

The fire in Building No. 5 was significant, largely attributed to the combustible interior lining material. The source emissive power from this fire was therefore considered to be a ‘high hazard’ exposure condition for purposes of regulation development. The peak radiant emissive power from Building No. 5 was approximately twice the peak radiant emissive power from Building No. 4, which had noncombustible interior lining. Therefore, for regulation development purposes, half of the peak result from Building No. 5, being 4.25 cal/cm²·s (178 kW/m²), was considered to represent a ‘low hazard’ exposure condition.

5.3 Exposed Source Criteria (Critical Incident Heat Flux)

With the radiant emissive power values established as described in **Section 5.2**, the next step was to establish a ‘critical’ incident radiant heat flux criteria upon which ‘acceptable’ distances could be calculated. The objective of limiting fire spread from one building to another was primarily concerned with building construction materials as the ‘exposed.’ The UK Department of Scientific and Industrial Research and Fire Offices’ Committee and the Joint Fire Research Organization had conducted studies of the ignition of wood [19, 21, 22]. At the time, wood was considered to be the building material with the lowest ignition temperature and associated ignition heat flux [22], and was therefore used to establish the critical incident heat flux upon which the UK regulations were developed. The same assumption was made in the development of the spatial separation regulations in the NBC [19], and based on the same research studies. These studies considered two types of ignition, pilot and spontaneous [22]. Pilot ignition requires a flame (or similar energy source) in proximity to the exposed surface for ignition to occur. On the other hand, spontaneous ignition does not require a pilot source for ignition to occur. Several species of wood were tested, and consistent results were found. These are summarized in **Table 5-2**.

Table 5-2: Critical heat flux for wood ignition.

Ignition Mechanism	Ignition Intensity (cal/cm²·s)
Pilot Ignition	0.3 (12.5 kW/m²)
Spontaneous Ignition	0.8 (33.5 kW/m²)

Pilot ignition was selected as the critical heat flux criteria. This was based on experience from actual fire events where sparks and flying brands were observed to be emitted from the fire, passing nearby adjacent structures and acting as a pilot ignition source [19]. Therefore, the critical heat flux criteria used in the development of the spatial separation regulations of the NBC was the pilot ignition of wood at 0.3 cal/cm²·s (12.5 kW/m²).

5.4 Critical Configuration Factor

The critical configuration factor is the geometrical relationship between the source emissive power and the critical heat flux. This relationship is expressed in **Equation 5-2**.

$$I_{crit} = \phi_{crit} \cdot E \qquad \textbf{Equation 5-2}$$

Where:

I_{crit} = Critical incident heat flux (cal/cm²·s)
ϕ_{crit} = Critical configuration factor
E = Emissive power of the openings (cal/cm²·s)

Rearranging **Equation 5-2** to solve for the critical configuration factor results in **Equation 5-3**.

$$\phi_{crit} = \frac{I_{crit}}{\mathrm{E}} \qquad \textbf{Equation 5-3}$$

Substituting the critical incident heat flux for wood (0.3 cal/cm²·s) and the emissive power for the 'high' (8.5 cal/cm²·s) and 'low' (4.25 cal/cm²·s) hazard exposure conditions results in the critical configuration factors summarized in **Table 5-3**.

Table 5-3: Critical configuration factors.

Hazard Level	Critical Configuration Factor
Low	0.070
High	0.035

These critical configuration factors are then used to represent the hazard characteristics of the exposing building (low or high) and the criteria to establish acceptable performance (ignition criteria). This means that where the configuration factor from an exposing building face to a point is less than the critical configuration factor, the incident heat flux at that point will be less than 0.3 cal/cm²·s (12.5 kW/m²), and the distance to the point as a function of those openings is then considered acceptable. Where the configuration factor is greater than the critical configuration factor, the heat flux will exceed 0.3 cal/cm²·s (12.5 kW/m²). In this case, the area/configuration of the openings would need to change, or the distance from the exposing building face to the point of interest increased to be acceptable.

5.5 Relationship Between Emissive Source and Exposed

Having characterized the hazard (Source Radiant Emissive Power) and the exposed (critical incident heat flux/configuration factor), a method was required to quantify the relationship between the hazard and the exposed. This relationship (configuration factor) can become mathematically complex, and difficult to apply in a simplified regulatory context without simplification and additional assumptions. In the development of the spatial separation regulations of the NBC, these include a basic planar configuration factor equation, a flame front factor, a mirror boundary consideration and application of the grey radiator concept to the exposing building face. These are discussed in the following sections.

5.5.1 GEOMETRICAL RELATIONSHIP (CONFIGURATION FACTOR)

The complexity of a configuration factor calculation depends on the shape of the source and its configuration (angle and distance) relative to a point of interest [23]. The configuration factor calculation for the spatial separation regulations has been simplified assuming [24]:

1. The exposing source is a rectangular vertical plane.
2. The exposed point of interest is parallel to and directly opposite the centre of the exposing plane.

This simplified relationship is illustrated in **Figure 5-4**, and the means to calculate the associated configuration factor is expressed in **Equation 5-4** to **Equation 5-6** [25, 26].

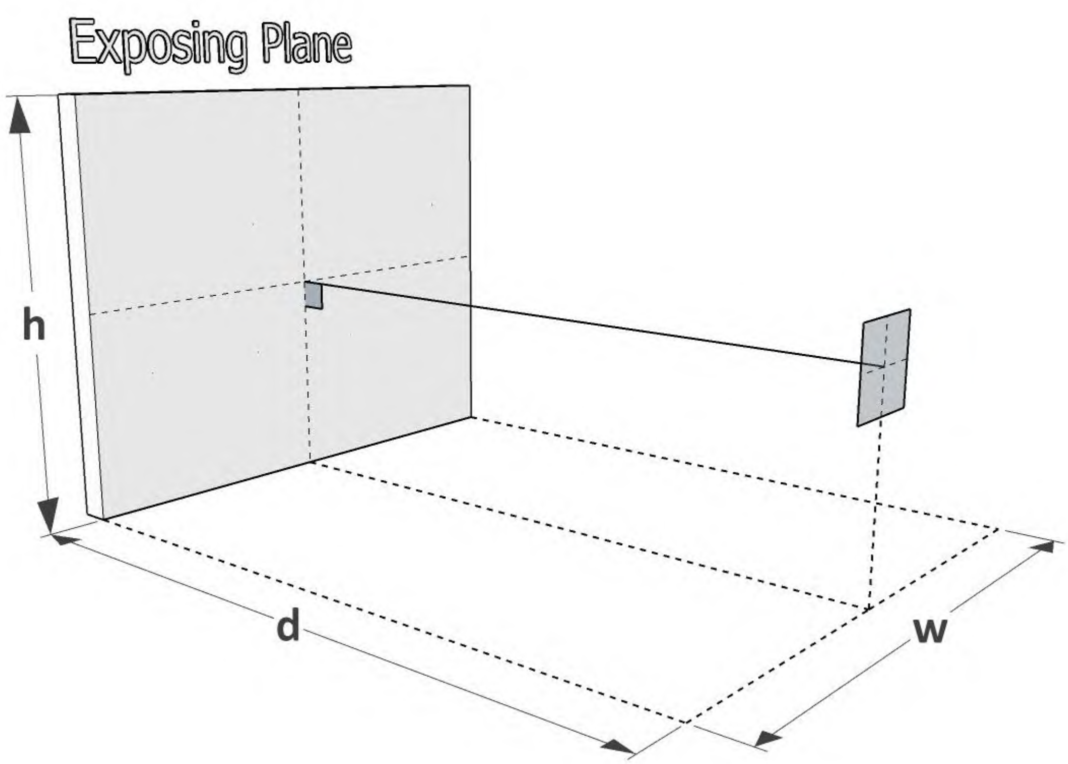

Figure 5-4: Basic planar configuration factor geometry.

$$\phi_{plane} = \frac{2}{\pi}\left[\sqrt{\frac{\frac{T}{S}}{\frac{T}{S}+4}}\tan^{-1}\left(\sqrt{\frac{T\cdot S}{\frac{T}{S}+4}}\right)+\sqrt{\frac{T\cdot S}{T\cdot S+4}}\tan^{-1}\left(\sqrt{\frac{\frac{T}{S}}{T\cdot S+4}}\right)\right] \quad \textbf{Equation 5-4}$$

$$\mathrm{T} = \frac{A}{d^2} = \frac{h\cdot w}{d^2} \quad \textbf{Equation 5-5}$$

$$\mathrm{S} = \max\left[\frac{h}{w},\frac{w}{h}\right] \quad \textbf{Equation 5-6}$$

Where:

ϕ_{plane}	=	Configuration factor
h	=	Exposing plane height (m)
w	=	Exposing plane width (m)
d	=	Distance from the exposing plane (m)
π	=	3.14159

One of the key variables in **Equation 5-4** is the ratio of the height to width (or vice-versa) as one of the key inputs to the NBC spatial separation tables, along with area and distance.

5.5.2 Flame Front

One of the objectives of the St. Lawrence burn tests was to examine flame extension from openings and the impact of wind on that flame extension [4]. The flame front results for the fire tests in Building Nos. 4 and 5 were discussed in **Section 4.3.1**. Based on these results, flame fronts of 1.5 m [5 feet] and 2.1 m [7 feet] were associated with the low and high hazard exposure conditions, respectively. These flame fronts were then applied as a modification to the distance (d) in the configuration factor calculation in **Section 5.5.1**. The reason for the flame front factor and the purpose of reducing the distance between the exposing plane and the exposed point was noted as follows [19, p. 10]:

> *This policy has been adopted firstly because the horizontal projections of flames from windows will not follow a linear geometrical relationship and secondly because firefighting becomes progressively more difficult with reduction in space separation.*

The two flame front values were later simplified into a single flame front of 6 ft (1.8288 m), being the average between the two previous values [27].

5.5.3 Limiting Distance

Limiting distance is not the actual distance between buildings, but a building independent representation of the distance. This concept was introduced in the 1941 NBC and further developed in the 1953 NBC to more pragmatically regulate building separation without having to directly implicate one's neighbour. In most design situations, the distance between a building and its property boundary is known, whereas the distance between neighbouring buildings may not be known. Therefore, the limiting distance is measured to a property boundary (or similar bounding line) and indirectly represents the 'safe' distance (**Section 5.5.1**) between the flame front (see **Section 5.5.2**) and a notional neighbouring building. This is expressed in **Equation 5-7**, and illustrated in **Figure 5-5**.

$$\mathrm{LD} = \frac{d+ff}{2} \quad \textbf{Equation 5-7}$$

Where:

LD	=	Limiting distance (m)
d	=	Theoretical distance between the flame front and a notional building (m)
ff	=	Flame front factor (6 ft or 1.8288 m)

The limiting distance concept introduces a 'mirror boundary condition,' whereby it is assumed that the notional building, located opposite the building under consideration, is of equal exposure risk. As a result, the theoretical distance may not be the actual distance between buildings, depending on the exposure characteristics of the building located opposite.

Equation 5-7 can be reorganized as shown in **Equation 5-8**. This can be used to calculate the theoretical distance and the associated configuration factor in **Equation 5-4** and **Equation 5-5**.

$$\mathrm{d} = 2 \cdot LD - ff \qquad \textbf{Equation 5-8}$$

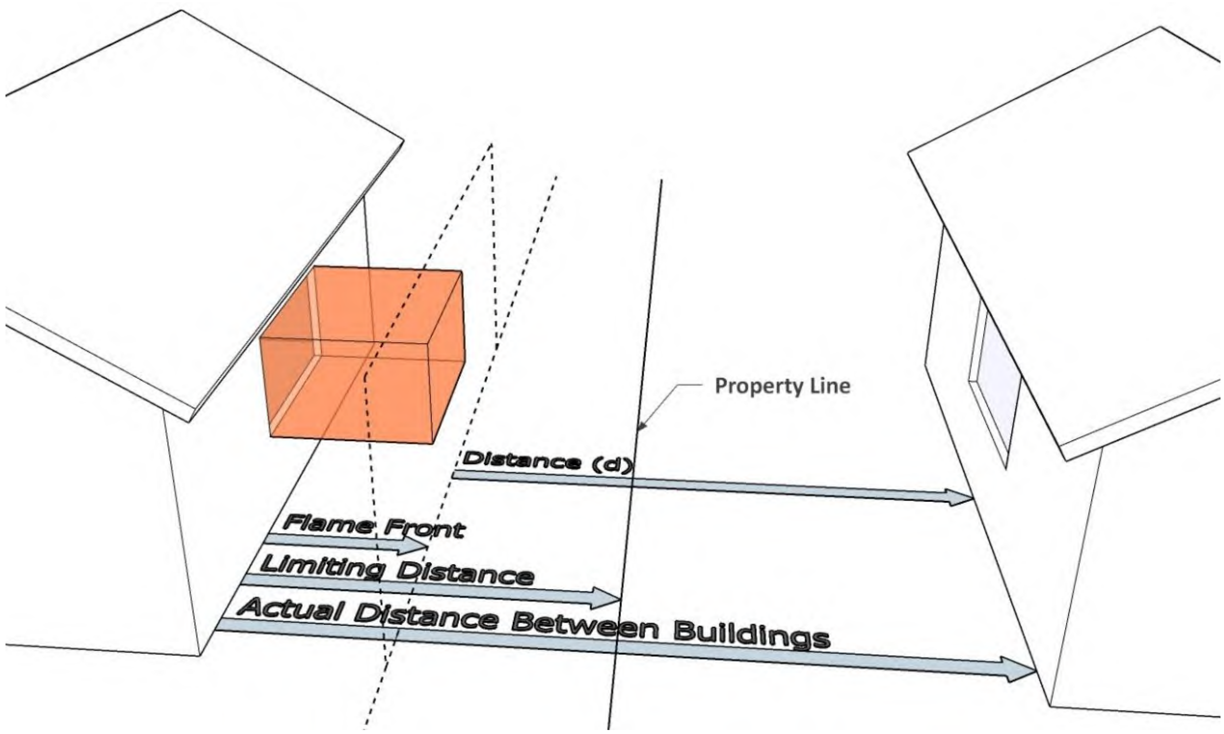

Figure 5-5: Exposing plane distances.

The 'mirror boundary condition' is a beneficial simplification; however, it breaks down where the actual building opposite has a different exposure risk. This can occur where the building opposite differs in occupancy, size, configuration, sprinklering, or combination thereof. An example is shown in **Figure 5-6** with a large building located opposite a small one. In this example, the critical heat flux boundary of the larger building is shown in orange, and encompasses the smaller building. The critical heat flux boundary of the smaller building is shown in yellow. The NBC warns of the potential for this condition in the following note [28, Div. B, p. 3-236]:

> *The Code requirements that deal with reducing the probability of building-to-building fire spread were originally developed based on the assumption that the exposing building faces of adjacent buildings are of similar size and configuration, and are equidistant from the shared property line. Where buildings are of different sizes, the smaller building may be subject to a higher heat flux in the event of a fire compared to the larger building.*

Where buildings are closely spaced and not equidistant from the property line, the construction of the building with the greater limiting distance does not recognize the proximity of the building with the lesser limiting distance.

In addition, the determination of the exposing building face as a function of fire compartment boundaries rather than an entire building face, mitigates the probability of such a discrepancy of exposure on opposite sides of a boundary. This is further supported by the trend of regulatory development in the NBC that has increased the degree of fire compartmentation.

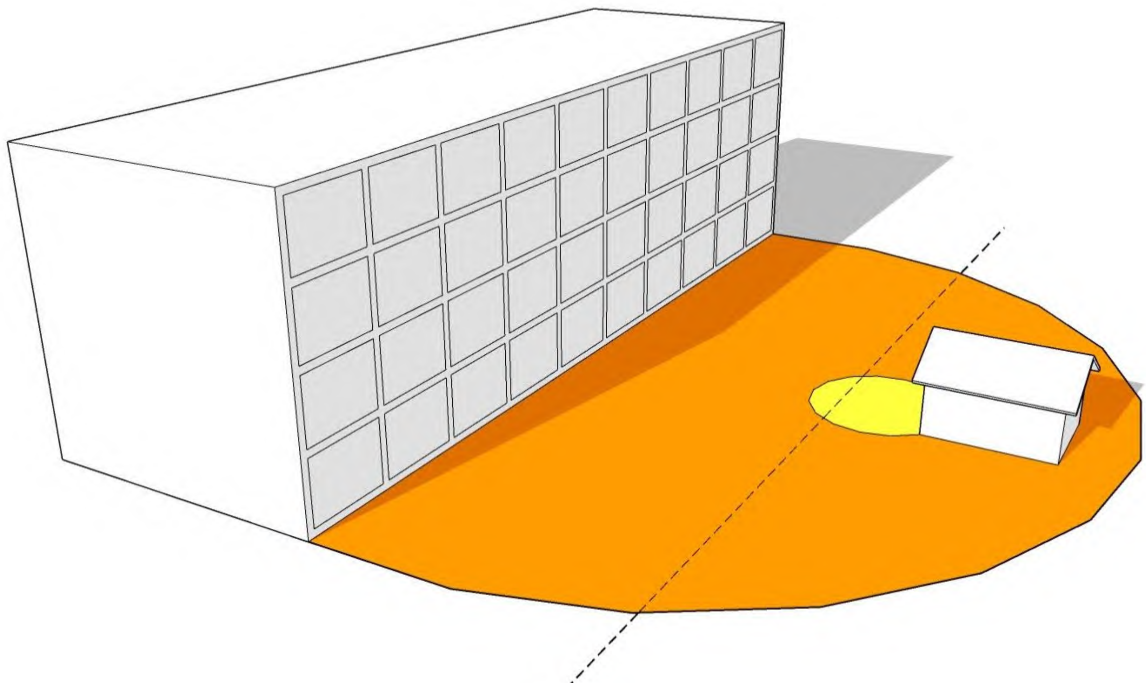

Figure 5-6: Mirror boundary condition.

5.5.4 GREY RADIATOR CONCEPT AND PERCENTAGE OF UNPROTECTED OPENINGS

As discussed in **Section 5.2**, the configuration factor from the face of each test building was determined as a summation of the configuration factors of all openings in that face. This calculation is cumbersome for even a few openings and, therefore, would be difficult to translate into regulations. The 'grey radiator concept' simplifies the configuration factor calculation by assuming the plane in which the openings are located is the emitting source, and expressing the openings in that plane as a percentage. The percentage is then applied to the configuration factor of the plane, similar to an emissivity [24], resulting in an effective configuration factor. This requires only a single configuration calculation, regardless of the number of openings. The grey radiator concept is expressed in **Equation 5-9** and illustrated in **Figure 5-7**.

$$\%\text{UPO} \cdot \phi_{plane} = \phi_{eff}$$ **Equation 5-9**

Where:

$\%\text{UPO}$ = Percentage unprotected openings in the exposing plane (%)
ϕ_{plane} = Configuration factor of the exposing plane
ϕ_{eff} = Effective configuration factor of the openings in the exposing plane

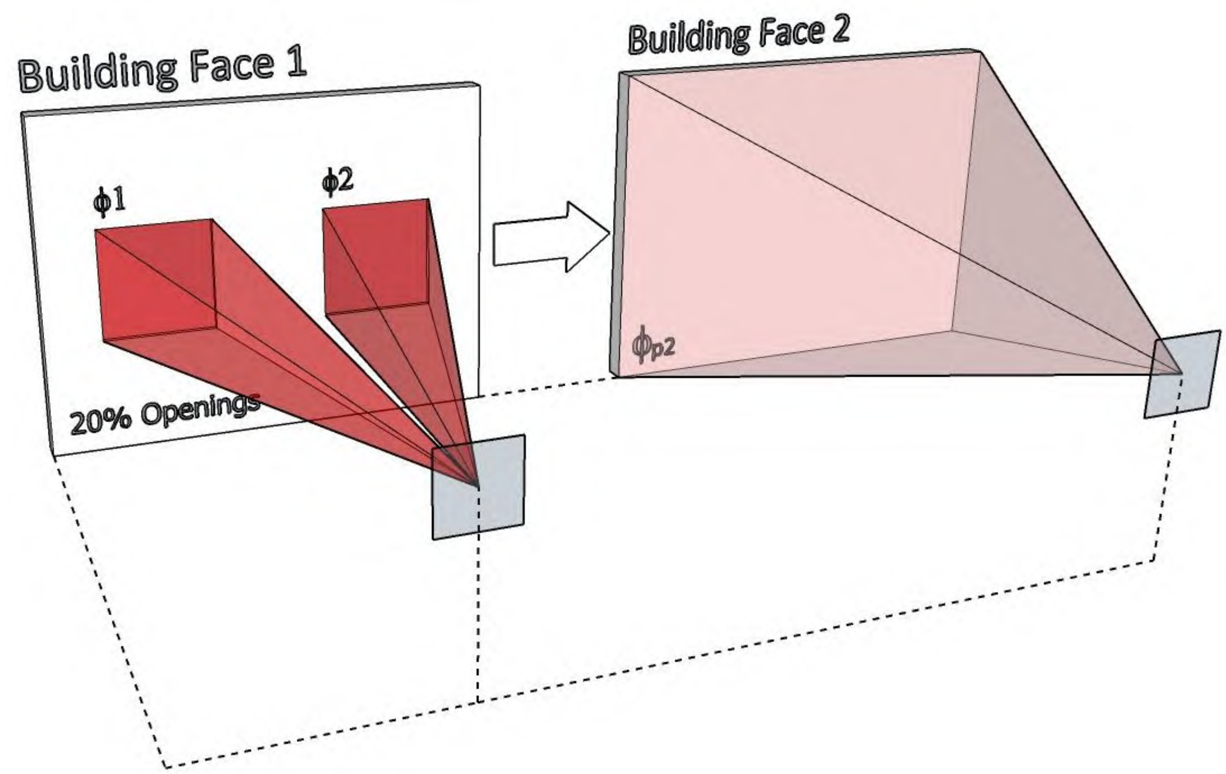

Figure 5-7: Grey radiator concept.

Figure 5-7 shows two exposing planes having the same area and aspect ratio. Exposing Plane 1 has two openings, with the radiant heat relationship (configuration factor) to the exposed point shown in red. Exposing Plane 2 represents the application of the grey radiator concept to the openings in Exposing Plane 1, where the openings are assumed to be evenly divided and distributed over the face of the plane. The relationship (configuration factor) to the exposed point is shown in pink. The result is expressed in **Equation 5-10**.

$$\phi_{bf1} = \phi_1 + \phi_2$$
$$\phi_{bf2} = 20\% \cdot \phi_{p2}$$
$$\phi_{bf1} \geq \phi_{bf2}$$

Equation 5-10

Where:

ϕ_{bf1}	=	Total configuration factor from building face 1
ϕ_{bf2}	=	Total configuration factor from building face 2
ϕ_1	=	Configuration factor of opening 1 in building face 1
ϕ_2	=	Configuration factor of opening 2 in building face 1
ϕ_{p2}	=	Configuration factor of the plane of building face 2

In order to allow a degree of flexibility in design, the spatial separation regulations of the NBC have been structured in terms of the 'grey radiator concept,' as a permitted percentage of unprotected openings. These are related to the critical configuration factor, and based on a reconfiguration of **Equation 5-9** to incorporate the critical configuration factor as shown in **Equation 5-11**.

$$\%\text{UPO} = 100 \cdot \left(\frac{\phi_{crit}}{\phi_{plane}}\right) \quad \textbf{Equation 5-11}$$

Therefore, given the height (h) and width (w) of an exposing building face, the distance of that building face to a property boundary (LD), the configuration factor of the exposing plane can be calculated using **Equation 5-4** to **Equation 5-6**, and **Equation 5-8**. The permitted percentage of unprotected openings in that building face can then be calculated using **Equation 5-11**. This provides a significant simplification to determining the configuration factor of multiple openings in the face of a fire compartment; however, still requires at least one configuration factor calculation. This is simplified further in the next section.

5.6 Table Simplification

This section specifically addresses the following Division B requirements of the 2020 NBC:

- Sentences 3.2.3.1.(1) to (4) and Tables 3.2.3.1.-B to 3.2.3.1.-E
- Sentences 3.2.3.2.(1) to (3)
- Sentence 9.10.14.4.(1) and Table 9.10.14.4.-A
- Sentence 9.10.15.4.(1) and Table 9.10.15.4.

Sentence 3.2.3.1.(1) references Tables 3.2.3.1.-B to 3.2.3.1.-E for the determination of the area of unprotected openings in an exposing building face. Sentences 3.2.3.1.(2) to (4) address and interpret how the percentage of unprotected openings are established and applied to other aspects of the NBC (i.e., exterior wall construction). The development of Tables 3.2.3.1.-B to 3.2.3.1.-E is detailed in the following sections.

5.6.1 Area of Exposing Building Face

Article 3.2.3.2. defines the boundaries of the area of an exposing building face, permitting the following:

1. the total area of an exterior wall facing in one direction on any side of a building measured from the finished ground level to the uppermost ceiling,
2. for each fire compartment provided the fire separations have a fire-resistance rating not less than 45 min, and
3. a storey basis for a sprinklered interconnected floor space.

Item 1 is the most limiting in terms of allowable unprotected openings and Item 3 recognizes the benefit of sprinkler protection by providing a relaxation that was introduced in the 1995 NBC based on the following rationale [29]:

> *In the case of interconnected floor space, it has been the practice of designers to treat each storey as a separate compartment for spatial separation purposes notwithstanding the presence of openings through the floor assemblies. The sprinklers are considered to control the fire spread vertically within the building and the same justification can be applied to the external face.*

With respect to Item 2, the NBC originally required a fire-resistance rating that aligned with the requirements of Subsection 3.2.2. However, a proposed change to the 1995 NBC recommended the fire-resistance rating be 45-min for all occupancies based on the following [30]:

Taking into consideration the presence of sprinklers, the need for rated floor assemblies and the fact that for buildings without sprinklers the maximum rating required for floor assemblies in buildings with no excessive fire loads is 1 hour, it is deemed to be sufficient to set the limit of 45 minutes for internal fire separations for the purposes of assessing the area of an exposing building face.

As a result, a fire compartment with fire separations having a 45-minute fire-resistance rating were allowed for all occupancies in characterizing the area of the exposing building face.

5.6.2 STANDARD TABLES

The permitted percentage of unprotected openings are tabulated as a function of occupancy (exposure hazard level), exposing building face area and ratio (function of height and width), and limiting distance. This allows the determination of the permitted percentage of unprotected openings with the configuration factor equations (**Equation 5-4** to **Equation 5-6**, **Equation 5-8** and **Equation 5-11**). However, this method is imprecise unless the input values align with the predefined table values. Where the input values do not align with the table's predefined inputs, either the closest table value is selected, or linear interpolation can be used.

5.6.3 SPRINKLER TABLES

The sprinklered spatial separation tables were developed in the 1995 NBC [31]. These tables were developed assuming a radiant emissive power that is approximately half the 'low hazard' exposure, or a critical configuration factor of 0.14. However, the sprinklered spatial separation table values were calculated by doubling of the 'low hazard' table values, and assuming a height to width ratio of 3.

Where a building is sprinklered, the 1965 NBC permitted the percentage of unprotected openings to be double the table value [32]. This option remained until the 1990 NBC [33]. During the effort to consider mandatory sprinklering of all Part 3 buildings in the 1990s, spatial separation tables were introduced instead of permitting a doubling of the unsprinklered table values. This change recognized the reliability of sprinklers in reducing the probability of fire growth and spread, and in particular spread as a result of exposure [29], by introducing minor simplifications of the underlying calculations of the permitted percentage of unprotected openings (i.e., **Equation 5-4** to **Equation 5-6**, **Equation 5-8** and **Equation 5-11**). Explanatory language in NFPA 80A, "Recommended Practice for Protection of Buildings from Exterior Fire Exposures" [18] was referenced in support of the minor simplifications associated with sprinklers.

Two key simplifications of the calculations were introduced [29]. The first was to apply an upper limit to the area of the exposing building face as a function of minimum permitted length of the area of sprinkler operation (sprinkler design area) in the sprinkler design standard referenced in the 1990 NBC (NFPA 13, 1989 edition [34]). This distance is calculated as shown in **Equation 5-12**.

$$\mathrm{L}_s = 1.2 \cdot \sqrt{A_s} \qquad \textbf{Equation 5-12}$$

Where:

L_s = Minimum length of the sprinkler design area parallel to the branch lines (m)
A_s = The area of sprinkler operation (m²)

The area of sprinkler operation (sprinkler design area) is established in NFPA 13 as a function of occupancy classification (i.e., light, ordinary and extra hazard). The minimum length of sprinkler design is then based on the minimum area of sprinkler operation permitted by NFPA 13 for low (light and ordinary) hazard occupancies and high (extra) hazard occupancies as shown in **Table 5-4**.

Table 5-4: NFPA 13 areas and minimum lengths of sprinkler operation.

Hazard Level (NBC)	Hazard Level (NFPA 13)	Area of Sprinkler Operation (m^2)	Minimum Length of Sprinkler Design Area (m)
Low	Light and Ordinary Hazard	139 (rounded to 140)	14.2 (rounded to 15)
High	Extra Hazard	232 (rounded to 240)	18.6 (rounded to 19)

A maximum compartment height of 10 m was assumed [29] (no rationale was provided for this assumption), and applied to the minimum lengths of sprinkler design area, resulting in exposing building face areas of 150 m^2 and 190 m^2 (rounded to 200 m^2) for low and high hazard exposures, respectively. These areas formed the upper limit of the sprinklered spatial separation tables of the NBC, assuming sprinklers will control the ultimate fire size to be within these limits.

The second simplification was to the ratio (S in **Equation 5-4** and **Equation 5-6**), which for sprinklered buildings was simplified to 3, based on limited changes to the permitted percentage of unprotected openings above that value [29].

The new sprinklered spatial separation table values were established based on the existing unsprinklered table values and the simplifications discussed above. However, the method used in establishing the permitted percentage of unprotected openings in the sprinklered tables resulted in further differences from values based on the fundamental equations underlying the spatial separation regulations.

6.0 CONCENTRATION OF OPENINGS

This section specifically addresses the following Division B requirements of the 2020 NBC:

- Sentences 3.2.3.1.(5) to (7) and Table 3.2.3.1.-A
- Sentences 9.10.14.4.(3) to (5) and Table 9.10.14.4.-B
- Sentences 9.10.15.3.(2), 9.10.15.4.(4) and (5)

Up until the 2005 NBC [35], the concentration of unprotected openings in an exposing building face was not regulated, even though localized concentrations of openings impact the effectiveness of the 'grey radiator concept' discussed in **Section 5.5.4**. A change was proposed to the 2005 NBC to regulate the concentration of unprotected openings, and better align those regulations with the intent of the 'grey radiator concept' [36].

An NRC discussion paper [37] examines the impact of a single rectangular opening in an exposing building face to determine the largest area as a function of limiting distance (based on T in **Equation 5-4**) that would correspond with the critical configuration factor of 0.07 (**Section 5.4**). The sensitivity of the configuration factor (ϕ) was examined with respect to changes to the ratio (S) between 0.3 and 1.0, and found to be negligible [37]. Therefore, 'T' in **Equation 5-4** was solved by equating ϕ = 0.07 and S = 1.0. The result, as illustrated below, is T = 0.24.

$$S = 1$$

$$\phi = 0.07 = \frac{2}{\pi}\left\{\sqrt{\frac{T}{T+4}}\tan^{-1}\left[\sqrt{\frac{T}{T+4}}\right] + \sqrt{\frac{T}{T+4}}\tan^{-1}\left[\sqrt{\frac{T}{T+4}}\right]\right\}$$

$$T = 0.237239 \approx 0.24$$

$$T = \frac{A}{d^2} = 0.24$$

Solving **Equation 5-5** for area (A), and substituting **Equation 5-8** (with only a 5 ft flame front) for the distance (d) results in **Equation 6-1** below.

$$A = 0.24 \cdot (2 \cdot LD - 5\, ft)^2 = 0.24 \cdot (2 \cdot LD - 1.5\, m)^2 \qquad \textbf{Equation 6-1}$$

Where:

A = Exposing opening area (m^2)
LD = Limiting distance (m)

The impact of localized concentrations of openings is considered to diminish with increased limiting distance. Therefore, a range of applicability of **Equation 6-1** was identified to be 1.2 m to 2.0 m [37]. Following this, a table of opening areas was calculated as a function of this range of limiting distances. However, the smallest area of 0.19 m^2, corresponding with a limiting distance of 1.2 m, was too small to be considered a bedroom "egress window" in accordance with the NBC. An egress window is required to be not less than 0.35 m^2 [Sentence 9.9.10.1.(2) of the 2020 NBC]. Therefore, in order to not impact egress window area, the flame front of **Equation 6-1** was arbitrarily lowered to 1.2 m to produce a result that would align with the minimum area required for a bedroom egress window. The modified version is expressed in **Equation 6-2**, and the corresponding table of values is included in **Table 6-1**.

$$A = 0.24 \cdot (2 \cdot LD - 1.2)^2 \qquad \textbf{Equation 6-2}$$

Table 6-1: Maximum area of individual unprotected openings.

Limiting Distance (m)	Maximum Area of Individual Unprotected Opening (m²)
1.2	0.35
1.5	0.78
2.0	1.88

Equation 6-2 and **Table 6-1** have both been included in the 2020 NBC, but are not applicable to sprinklered buildings. In addition to the maximum area of individual openings, the minimum separation between openings serving the same room is required to be at least 2 m [28].

Sentences 3.2.3.1.(6) and (7) address the application of Sentence 3.2.3.1.(5) relative to separate rooms or spaces, which are quantified as follows:

- two or more adjacent spaces having a full-height separating wall extending less than 1.5 m from the interior face of the exterior wall, or
- two or more stacked spaces that are on the same storey.

The 'justification' for the code change in support of the addition of Sentences 3.2.3.1.(6) and (7) is noted in the 2008 public review package as follows:

> *Maximum concentrated area of unprotected opening [Sentence (5)] can be determined from a simple table or by calculation, which would provide more case-specific values that may be less stringent. Minimum spacing between openings [Sentence (6)] is specified as a single 2 m limit. The application of Sentence (6) only to openings that serve the same room or space recognizes that interior partitions provide some resistance to spread of fire. The space adjoining the space of fire origin will not become involved in the fire immediately. Consequently, although an unprotected opening in an adjoining space may be close to an unprotected opening in the space of fire origin, it will not add to the radiant heat flux from the subject building until the interior partition is compromised.*

The concept and explanation of a "single room or space" were first introduced in the 2010 NBC. The premise assumes that fire growth and progression within one room will experience a delay before spreading to an adjacent room. This implies that while the room where the fire originates might transition through flashover and become fully involved, the adjacent room's progression to full involvement may be delayed due to the separation between the two spaces. The term "single room or space" was initially defined in relation to criteria used to determine whether two rooms qualify as a "combination room."

> *two or more areas shall be considered to be a single room or space where there is an opening between the two areas that is no less than the larger of 3 m² or 40% of the area of the separating wall.*

For context, the definition of a combination room at that time was specified as follows [Sentence 9.5.1.2.(1) of the 2005 NBC]:

> *Two or more areas may be considered as a combination room if the opening between the areas occupies the larger of 3 m² or 40% or more of the area of the wall measured on the side of the dependent area.*

The definition of a combination room mentioned above was removed in the 1995 NBC but was included in the 2005 NBC. A portion of the appendix note accompanying the definition of a combination room is provided below [Appendix Note A-9.5.1.2.(1) of the 2005 NBC]:

> *a minimum opening of 3 m^2 is required, or the equivalent of a set of double doors.*

Assuming a double set of doors is approx. 1.5 m (5 ft) wide and 2.0 m (6 ft. 8 in.) in height results in a door (opening) area of 3.0 m^2. If this area is 40% of the wall, the wall area is 7.5 m^2. Assuming a typical ceiling height of 2.4 m (8 ft), the width of the wall is 3.1 m. Assuming the door is furthest from the exterior wall and subtracting the door width results in a wall extending 1.6 m from the interior face of the exterior wall. Therefore, the “1.5 m from the interior face of the exterior wall” is likely related to the definition of a combination room.

7.0 FIRE DEPARTMENT ARRIVAL (10 MINUTES)

This section specifically addresses the following Division B requirements of the 2020 NBC:

- Sentence 3.2.3.1.(8)
- Sentence 9.10.14.3.(1)
- Sentence 9.10.15.3.(1)

Up until the 1970 NBC [38], the assumption of fire service intervention underpins the establishment of the radiant emissive power in the development of the spatial separation regulations (**Section 5.2**) was not included as part of those regulations. However, a note was included in the 1965 NBC and 1970 NBC to the application of the spatial separation regulations as follows [38, p. 86]:

> *The requirements of this Article are based on the assumption that properly equipped fire-fighting services are available. The limiting distances required herein can be relied upon only when a fire is in its incipient stages. Where a properly equipped fire-fighting service is not available, the required distances should be double the distances specified.*

This note was proposed to be changed in the 1975 NBC to reference [39, p. 83] “It has been found that periods of some 10 to 30 minutes usually elapse between the outbreak of flaming combustion.” However, in addition to the revision of the note, a specification was added as a package of revisions to the 1970 NBC [40]. The specification required the following [41, p. 87]:

> *In respect to the building under consideration where firefighting facilities and protective wetting facilities are not available within 10 min. of the alarm being received, the limiting distance required by Article 3.2.3.1. shall be doubled.*

Other than editorial revisions, this specification remained unchanged until the 2005 NBC [35]. The 2010 NBC included an update to this specification to add clarity in its application, add performance metrics to the specification, and provide an exemption for sprinklered buildings [42]. The current requirement is as follows [28, Div. B, p. 3-79]:

> *8) A limiting distance equal to half the actual limiting distance shall be used as input to Tables 3.2.3.1.-B and 3.2.3.1.-C, where*
>
> *a) the time from receipt of notification of a fire by the fire department until the arrival of the first fire department vehicle at the building exceeds 10 min in 10% or more of all fire department calls to the building, and*
>
> *b) any storey in the building is not sprinklered.*

The result of this specification is that for locations a distance from a firehall, or rural areas, the permitted percentage of unprotected openings in exterior walls is reduced, or the distance from the property boundary is required to be increased to allow the same quantity of unprotected openings.

8.0 STAGGERED OR SKEWED EXPOSING BUILDING FACES OF HOUSES

This section specifically addresses the following Division B requirements of the 2020 NBC:

- Subclause 9.10.15.2.(1)(b)(iii) and Sentence 9.10.15.4.(2)

Subclause 9.10.15.2.(1)(b)(iii) and Sentence 9.10.15.4.(2) allows for the determination of the area of an exposing building face based on the area of any number of individual portions of the exposing building face, and then allows the determination of the maximum aggregate area of glazed openings for any portion to be determined using the values in Table 9.10.15.4. corresponding to

a) the maximum total area of exposing building face, which is equal to the sum of all portions of the exposing building face, and

b) the limiting distance of each portion.

The explanatory note to Sentence 9.10.15.4.(2) provides guidance and diagrams on the application of this concept [A-9.10.15.4.(2) of the 2020 NBC]. These requirements were developed based on an analysis conducted by Kuma Sumathipala [43] comparing the configuration factor from unprotected openings in angled and stepped exposing building faces using a fundamental configuration factor equation (similar to **Equation 5-4**).

The results of this analysis show that the modified method of calculating the configuration factor and associated percentage of permitted unprotected openings for stepped and angled faces are lower than those of the parallel face [43]. Therefore, this approach provides greater design flexibility.

9.0 EQUIVALENT OPENING AREA

This section specifically addresses the following Division B requirements of the 2020 NBC:

- Sentences 3.2.3.1.(9) and (10)

Sentence 3.2.3.1.(9) addresses wall assemblies that have a surface temperature on the unexposed surface of the wall assembly that exceeds the temperature limit of a standard fire test. This is addressed by requiring an area of unprotected openings that correlates to the increased surface temperature, based on the following equation:

$$F_{EO} = \frac{(T_u + 273)^4}{(T_e + 273)^4}$$ **Equation 9-1**

Where:

F_{EO} = Equivalent opening factor
T_u = Unexposed wall surface average temperature at the time the required fire-resistance rating is reached under test conditions (°C)
T_e = 892°C for a fire-resistance rating not less than 45 min, 927°C for a fire-resistance-rating not less than 1 h, and 1010°C for a fire-resistance rating not less than 2 h

$$A_C = A + A_F \cdot F_{EO}$$ **Equation 9-2**

Where:

A_C = Corrected area of unprotected openings including actual and equivalent openings (m²)
A = actual area of unprotected openings (m²)
A_F = Area of exterior surface of the exposing building face, exclusive of openings, on which the temperature limit of the standard test is exceeded (m²)

This requirement was first introduced in the 1970 NBC and is intended to address potential exposure from radiant heat from the unexposed surfaces of these assemblies. **Equation 9-1** provides a ratio of the radiant heat expected from the actual wall assembly to the radiant heat corresponding with the time-temperature of the required fire-resistance of the wall. This ratio is similar to the grey radiator concept discussed in **Section 5.5.4** (i.e., an effective emissivity). Applying the equivalent opening factor to the blank area of the wall allows for a calculation of the area that would otherwise be equivalent to an unprotected area (i.e., the area representing the full standard test temperature at the corresponding fire-resistance time).

In addition, Sentence 3.2.3.1.(10) was added to the 1995 NBC with the following rationale [44]:

> *Changes were made in the NBC 1990 to permit the use of closures to protect openings in an exposing building face. As it was realized that few closures have the necessary resistance to the increase of temperature on the unexposed side that is expected of the wall assembly, it was intended that designers would apply the principles of 3.2.3.12. [Now Sentence 3.2.3.1.(9)] to determine the equivalent opening for purposes of limiting distance calculation. In the absence of a specific statement to that effect in the NBC, designers and authorities have been left without direct guidance concerning the intent of the committee. This change will clarify the intent of the committee.*

However, the addition of this requirement has created a challenge in practical application without available test data for closure to allow for the determination of (T_u), the "unexposed wall surface average temperature at the time the required fire-resistance rating is reached under test conditions."

10.0 CONCLUSION

This report has detailed the historical development of the spatial separation requirements of the NBC with a focus on the development of Articles 3.2.3.1. and 3.2.3.2., Tables 3.2.3.1.-A to 3.2.3.1.-E in Part 3 and Articles 9.10.15.1. to 9.10.15.4., Tables 9.10.14.4.-A, and 9.10.15.4. in Part 9 of Division B. The report has identified the current performance targets and calculation and evaluation methods. The following is recommended based on the analysis:

1. Review the applicability of the flame front factor included in the development of the table values.
2. Reconsider the 10-minute fire department response time related to original St. Lawrence test burn timing.
3. Examine the flame front factor and low hazard critical configuration factor used to establish the requirements associated with concentration of openings.
4. Consider utilizing the approach to stepped and angled building faces permitted in Part 9 to be applicable to larger buildings (Part 3).

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