How to Use Fire Risk Assessment Tools to Evaluate Performance–Based Designs

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1 ABSTRACT

Performance-based regulations allow the designers and building officials the freedom to come up with innovative designs that will provide a level of safety that satisfies the objectives established by the regulations. Such innovative designs often lead to lower fire protection costs. The implementation of performance-based building regulations can be facilitated by the development of engineering tools that can help assess the overall fire safety performance of a building. This paper presents two fire risk assessment models, FIERAsystem and FiRECAM™, which can be used as equivalency and performance-compliance design tools for cost-effective fire safety designs. The paper also describes two case studies using these tools in order to demonstrate their utility in evaluating performance-based designs.

2 INTRODUCTION

In the event of a fire occurring in a building, the occupants would normally attempt, if possible, to evacuate the building. If, however, the fire and smoke conditions in the building are such that it is not possible to evacuate, then the occupants may have no choice but to return to their respective compartments and wait for the firefighters to arrive at the fire scene to suppress the fire and to rescue them. To help the occupants evacuate the building before the building becomes untenable, building regulations typically require that fire safety measures, such as fire detection, fire suppression, smoke control, and fire resistance systems, are in place to prevent the spread of fire and smoke and to provide occupants with adequate time to evacuate. The level of fire safety that is provided to the occupants depends on how well the fire safety systems work.

To help ensure that the required level of fire safety is provided to the occupants, many countries in the world have introduced, or are planning to introduce in the near future, performance-based regulations. In these regulations, the performance of fire safety systems is specified, whereas in the existing prescriptive regulations, only the installation and maintenance of certain fire safety systems are specified. Performance-based regulations allow the designers and building officials the freedom to develop innovative designs that will provide a level of safety that satisfies the objectives established by the regulations. Such innovative designs can often lead to lower fire protection costs. The implementation of performance-based building regulations can be facilitated by the availability of engineering tools that can help assess the overall fire safety performance of a building.

To provide tools that can assess the overall fire safety performance of a building, the National Research Council of Canada (NRC) has been developing two risk-cost assessment models called FiRECAM™ (Fire Risk Evaluation and Cost Assessment Model) and FIERAsystem (Fire Evaluation and Risk Assessment system). FiRECAM™ can assess both the expected risks to life of the occupants in a building, as well as the expected costs of fire protection and fire losses in the building. Therefore, the model can be used to identify cost-effective fire safety designs that provide the level of safety that is required by the code, or alternative designs that provide a level of safety that is equivalent to that of a code-compliant design. FIERAsystem, a computer model to evaluate fire protection systems for light industrial buildings, is based on a framework that allows designers to establish objectives, select possible fire scenarios, and evaluate the impact of each scenario on life safety and property protection. Australia is the only other country developing a tool, called CESARE-RISK (1998), that is similar to NRC’s tools.

First, this paper briefly outlines the frameworks for FIERAsystem and FiRECAM™ and their main sub-models. Then, in order to show the utility of FIERAsystem and FiRECAM™ in evaluating performance-
based designs, two case studies are presented. The first case shows the compliance with a set of objectives, for various fire safety design options, inside a building using FIERAsystem. For the purpose of this study, a 3-storey building is used as the basis for all analyses. Evaluation of the objectives is based on fire development, fire and smoke spread in the building, and the evacuation of occupants through corridors and stairs to safety at ground level. The second case deals with evaluating equivalency in designing buildings. For this, FiRECAM™ is used to show how the impact of different fire safety design options on life safety can be assessed. An 8-storey building is used to demonstrate how the model works. Based on the results, the designer could choose the option that provides high safety with low cost.

3 DESCRIPTION OF FIERASYSTEM

FIERAsystem uses time-dependent deterministic and probabilistic models to evaluate the impact of selected fire scenarios on life, property and business interruption. FIERAsystem allows the user to perform a number of fire protection engineering calculations using standard engineering correlations, individual sub-models, hazard analysis, or risk analysis in order to evaluate fire protection systems in industrial buildings. The standard engineering correlations model is a collection of relatively simple equations and models that can be used to quickly perform simple fire protection engineering calculations. The main FIERAsystem models include fire development, smoke movement, fire detection, building element failure, suppression effectiveness, fire department response and effectiveness, occupant response and evacuation, life hazard, expected number of deaths, economics, and downtime. Detailed information on the sub-models can be found in Benichou et al. (2002). Hazard analysis is the process of running all pertinent sub-models to calculate the number of deaths and property losses in a building for a specified fire scenario. Risk analysis consists of performing hazard analysis of a number of fire scenarios, and then calculating the risk using the probability of the scenarios considered. In addition, FIERAsystem can be used to evaluate whether or not a fire protection system for a building will satisfy specific fire safety objectives. The design of FIERAsystem was made flexible to allow its use by designers of different types of buildings, since modifications can be made to individual sub-models, without having to change the rest of the system model.

3.1 Calculation Process in FIERAsystem

Following the approach of performance-based codes, FIERAsystem is based on a framework that allows designers to establish objectives, select fire scenarios and evaluate the impact of each of the selected scenarios on life safety, property protection and business interruption. The FIERAsystem framework leads the user through a series of steps in setting up the problem:

- Define building characteristics.
- Define occupant characteristics.
- Identify fire safety objectives and performance criteria.
- Identify potential fire scenarios.
- Select fire protection options, including passive and active fire protection systems.
- Select calculation procedures such as using standard engineering correlations, running individual sub-models, or conducting a hazard or risk analysis.

As the case study in this paper focuses on the fire safety objectives and performance criteria, and how FIERAsystem evaluates their compliance, in the following section, the methodology to evaluate fire safety objectives is explained in detail.

3.2 Process of Satisfying the Objectives

Once the applicable objectives are defined, the system will execute the appropriate sub-models to determine whether the specified designs satisfy the acceptance criteria. The following paragraphs explain how the objectives and criteria are evaluated.

Fire development: FIERAsystem compares the fire size calculated by the fire development and suppression effectiveness sub-models, in order to evaluate compliance with the objective based on fire size. In addition, FIERAsystem compares the time to flashover calculated by the fire development,
suppression effectiveness, and smoke movement sub-models, or the standard engineering correlation
module in order to evaluate compliance with the objective based on time to flashover.

Life safety: The objective of no critical conditions being reached in the fire compartment, escape routes,
and areas of refuge before a period of time is evaluated, based on information from the fire development,
smoke movement, and the life hazard sub-models. The objective of no occupants subjected to critical
conditions is evaluated based on information from the fire development, smoke movement, occupant
response and evacuation, and the life hazard sub-models. Using the time to reach untenable conditions in
the escape routes and the time for occupants to respond and evacuate, FIERA system can evaluate
whether occupants have successfully escaped to a safe place without being impacted by critical conditions.
Critical conditions are performance measures of the levels of heat and toxic species in the escape routes
and building compartments.

Smoke spread: The smoke movement objective is evaluated by the smoke movement sub-model. Given
the information on the temperature and thickness of smoke layers and species concentrations in the
adjacent compartments, FIERA system can evaluate whether smoke has spread, and thus gives a pass/fail
flag to the user.

Fire spread: The objectives related to limiting fire spread within the building, are evaluated by comparing
the time calculated by the boundary element failure and the time of critical radiation levels calculated by the
smoke movement sub-models to the established acceptance criteria. Fire spread to adjacent buildings is
also evaluated by the radiation to adjacent buildings and fire department response sub-models.

Economics: Business interruption is estimated using the expected number of days of interruption due to the
size of fire, a flashover event, heat fluxes and smoke concentration. The total number of days of
interruption is then compared to the acceptance criterion. Damages to the building and its contents
are estimated by the economic sub-model based on the selected fire scenarios. These damage estimates can
then be used along with the cost information to estimate the value of the property loss to the building and
its contents. The estimates are then compared to the acceptance criteria.

4 DESCRIPTION OF FIRECAM™

FiRECAM™ can assess both the expected risks to life of the occupants in a building, as well as the
expected costs of fire protection and fire losses in the building. The separation of life risks and protection
costs in FiRECAM™ avoids the difficulty of assigning a monetary value to human life and allows the
comparison of risks and costs, separately. The expected risks to life (ERL) value can be used for
performance compliance or code equivalency consideration, whereas the expected costs of fire value can
be used for cost-effectiveness considerations. Therefore, the model can be used to identify cost-effective
fire safety designs that provide a level of safety that is required by the code, or alternative designs that
provide a level of safety that is equivalent to that of a code-compliant design.

To undertake the evaluation of fire risks and losses, FiRECAM™ simulates the ignition of a fire in
various locations in a building, the development of the fire, smoke and fire spread, occupant response
and evacuation, and fire department response. These calculations are performed by a number of sub-models
interacting with each other as shown in Figure 1. FiRECAM™ is a comprehensive model that includes the
probability of fire spread in a building, the response of the fire department and the estimate of fire costs, in
addition to the typical modelling of fire growth, smoke spread and evacuation.

FiRECAM™ uses statistical data to predict the probability of occurrence of fire scenarios, such as the
type of fire that may occur or the reliability of fire detectors. Mathematical models are used to predict the
time-dependent development of fire scenarios, such as the development and spread of a fire and the
 evacuation of occupants in a building. The life hazard posed to the occupants by a fire scenario is
calculated based on how quickly the fire develops and how quickly the occupants evacuate the building for
that scenario. The life hazard calculated for a scenario multiplied by the probability of that scenario gives
the risk to life from that scenario. The overall expected risk to life to the occupants is the cumulative sum of
all risks from all probable fire scenarios that may occur in a building. Similarly, the overall expected fire
cost is the sum of fire protection costs (both capital and maintenance) and the cumulative sum of all fire
losses from all probable fire scenarios in a building. Details of the model can be found in Yung et al. (1999).

5 CASE STUDY USING FIERASYSTEM – COMPLYING WITH A SET OF OBJECTIVES

This case study is a demonstration of the compliance with a set of objectives, for various fire safety design options, inside a building. For the purpose of this case, a 3-storey building is used as the basis for all analyses, chosen because it represents a typical building found in many Canadian cities (see Figure 2). The evaluation of the objectives is based on the fire development, fire and smoke spread in the building, and the evacuation of occupants through corridors and stairs to safety at ground level. The building is of concrete construction and has a square shape with a total area of 400 m² (20 m by 20 m). The first level has three compartments representing a restaurant and a bookstore, separated by a 2.5-m corridor. The restaurant has 2 separate compartments, a kitchen and a seating area. On the second level, there is a dentist’s office and a medical laboratory. The area of the compartments on the first and second floors is 350 m² (for each floor). The third level is an open space software engineering office and is assumed to have an area of 400 m². The building has two stair shafts at the two ends of the corridor.

5.1 Definition of Occupant Load and Characteristics

The number of occupants varies with the location. The total number of occupants in the building is 112, representing about 1 person per 10 m². Table 1 shows the occupant load in each compartment along with their characteristics. The occupants are assumed to evacuate through the stairs. If the stairs become untenable, they are assumed to stay in their compartment units waiting to be rescued by firefighters when they arrive.
### TABLE 1. Occupant load and characteristics

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Maximum Occupant load</th>
<th>Special needs</th>
<th>Children</th>
<th>Seniors</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurant Seating Area</td>
<td>47</td>
<td>1</td>
<td>5</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>Kitchen</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Bookstore</td>
<td>20</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Dentist’s Office</td>
<td>15</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Medical Laboratory</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Engineering Office</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

### 5.2 Identify Fire Safety Objectives and Appropriate Performance Criteria

1. No flashover in the room of fire origin before complete evacuation of occupants not intimate with the fire.
2. No occupants subjected to critical conditions.
3. No fire spread to adjacent compartments before fire department intervention.
4. No fire spread to adjacent buildings before fire department intervention.
5. No interruption of adjacent businesses before fire department intervention.
5.3 Identify Potential Fire Scenarios

The potential design fire scenarios have the fire development characteristics shown in Table 2. For the analysis, only the worst-case scenario will be used, which in this case is likely to be the scenario in the restaurant kitchen.

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$\alpha$ (1) (kW/s²)</th>
<th>Maximum HR (2) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurant</td>
<td>0.0469 (Fast)</td>
<td>6</td>
</tr>
<tr>
<td>Seating area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>0.0469 (Fast)</td>
<td>6</td>
</tr>
<tr>
<td>Bookstore</td>
<td>0.0469 (Fast)</td>
<td>6</td>
</tr>
<tr>
<td>Dentist’s Office</td>
<td>0.0469 (Fast)</td>
<td>6</td>
</tr>
<tr>
<td>Medical Laboratory</td>
<td>0.0469 (Fast)</td>
<td>6</td>
</tr>
<tr>
<td>Engineering Office</td>
<td>0.0117 (Medium)</td>
<td>6</td>
</tr>
</tbody>
</table>

Note: (1) $\alpha$ – fire growth coefficient  (2) HR – heat release

5.4 Fire Protection Options

Three different fire safety design options were considered for analysis and are summarized in Table 3.

<table>
<thead>
<tr>
<th>Option</th>
<th>Sprinkler system</th>
<th>Smoke detection</th>
<th>Alarm</th>
<th>Fire compartment door conditions</th>
<th>Fire resistance rating (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>Throughout</td>
<td>Central</td>
<td>Open (100% open)</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>Throughout</td>
<td>Central</td>
<td>Open with self closing device (50% open)</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>Yes</td>
<td>Throughout</td>
<td>Central</td>
<td>Open (100% open)</td>
<td>60</td>
</tr>
</tbody>
</table>

5.5 Results and Discussion

5.5.1 Results with fire in restaurant kitchen for design option 1

To carry out the analysis, the scenarios listed in Table 2 were considered and the results were compared. Due to space limit, only the results for the fast fire scenario that occurs in the restaurant kitchen, for design Option 1, will be shown in this paper. For this option, however, this scenario was found to be the worst-case scenario, and will provide the worst fire conditions in the building compared to the other scenarios.

To show the dynamic interaction between the development of heat and smoke in the compartment of fire origin and the egress of the occupants, the results for the restaurant scenario, for Option 1, are shown in Figures 3 and 4. Figure 3 shows the heat release rate vs. time in the restaurant kitchen and the software engineering office (for illustration only), as predicted by the fire development model with a maximum heat release rate of 6 MW. In the kitchen, the fire reached a peak heat release rate of 6 MW at a time of 360 s and the flashover occurred at 270 s. The fire development in the engineering office shows a slower growth rate than the kitchen and reaches the maximum 6MW at around 720s.

Figure 4 shows the smoke movement model predictions in terms of the temperature and depth of the hot layer, and CO and CO$_2$ productions with time in the room of fire origin (kitchen). The temperature increases rapidly for 200 s up to about 300°C, after which it drops to 250°C at 250 s. This drop corresponds to the time when the kitchen glass breaks and the cooling effect from it. After 250 s, the temperature starts increasing again and reaches 730°C at the end of the simulation. The temperature in the staircase is much lower than that in the kitchen because the gases generated from the fire in the kitchen cool down as they move through the seating area and corridor. The depth of the hot layer in the kitchen increases from zero at the ceiling, at ambient temperature, to 2.84 m at 1000 s. The layer reaches a depth of 1.5 m (1.5 m from the floor level) at about 150 s, which represents the untenable depth to occupants in the restaurant kitchen. The depth of the layer (cold) in the staircase starts almost flat up to 170 s, then increases rapidly to 8.5 m (from the staircase ceiling) in 350 s, where it stays until the end of the simulation. The predictions of CO and CO$_2$ concentrations in the kitchen indicate a rapid increase in
CO and CO₂ at the start of the fire for about 400 s and then a plateau at a concentration of 2400 ppm of CO and 10% of CO₂ after about 500 s. As in the case of the hot layer temperature in the kitchen, the CO drops from 1450 ppm at 200 s to 1000 ppm at 250 s, then starts increasing, due to glass breakage in the kitchen and dilution of CO with fresh air.

Figure 3. Heat release curves for the restaurant kitchen and engineering office

Figure 4. The build-up of smoke and heat in the kitchen and staircase

5.5.2 Evaluation of the objectives

FIERA System was used to evaluate compliance with the objectives for all scenarios and design options shown in Tables 2 and 3, respectively. For the purpose of this case study, the objectives were evaluated using the stand-alone sub-models. Table 4 shows a summary of the results of the analysis for different events for the design options.

Performance solution for Option 1: Option 1 has a central alarm, smoke detection, 60 min Fire Resistance Rating (FRR), and the doors of the restaurant, bookstore and one staircase to the 1st floor corridor are open at all times. For this option, the fire was detected at 22 s, and flashover occurred at 270 s, while complete evacuation occurred at 272 s; thus Objective 1 was not achievable. The difference of 2 s may seem very small, but when safety factors are applied to the evacuation time, this difference becomes more significant. On the first floor, lethal conditions happened very fast because of flashover and spread of hot and toxic gases. On the other floors, lethal conditions did not occur during the simulation, because the doors were closed to these levels. The time required for complete evacuation was 272 s while untenable conditions in the staircase occurred at 410 s. This allowed all occupants to make it to a safe location; therefore Objective 2 was satisfied. Fire spread to adjacent compartments, adjacent businesses and adjacent buildings could occur at the earliest at 75 min. The fire department response and intervention were 495 s and 795 s, respectively, and therefore much shorter than the fire spread. This concludes that Objectives 3, 4, and 5 were satisfied. To be compliant with the established objectives, the designer should
upgrade the fire safety system to allow occupants to evacuate faster and untenable conditions to occur more slowly.

Performance solution for Option 2: Option 2 is the same as Option 1 but with doors with self-closing devices, which were assessed to be open 50% of the time. This option slows down the migration of toxic and hot gases to the other locations, giving a better chance to occupants to evacuate before untenable conditions are reached. The detection and flashover times are the same as Option 1. Although this option limited the door opening, it satisfied all objectives but the first one that required complete evacuation (occurred at 272 s) before flashover (occurred at 270 s).

TABLE 4. Results of analysis

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection time</td>
<td>22 s</td>
<td>22 s</td>
<td>22 s</td>
</tr>
<tr>
<td>Time to flashover in kitchen</td>
<td>270 s</td>
<td>270 s</td>
<td>No flashover</td>
</tr>
<tr>
<td>Time required to evacuate</td>
<td>272 s</td>
<td>272 s</td>
<td>301 s</td>
</tr>
<tr>
<td>Fire department response</td>
<td>495 s</td>
<td>495 s</td>
<td>482 s</td>
</tr>
<tr>
<td>Fire department intervention</td>
<td>795 s</td>
<td>795 s</td>
<td>782 s</td>
</tr>
<tr>
<td>Time to reach untenable conditions in staircase</td>
<td>410 s</td>
<td>525 s</td>
<td>540 s</td>
</tr>
<tr>
<td>Time for fire spread to adjacent compartments</td>
<td>No spread</td>
<td>No spread</td>
<td>No spread</td>
</tr>
<tr>
<td>Time for fire spread to adjacent businesses</td>
<td>No spread</td>
<td>No spread</td>
<td>No spread</td>
</tr>
<tr>
<td>Time for fire spread to adjacent buildings</td>
<td>No spread</td>
<td>No spread</td>
<td>No spread</td>
</tr>
<tr>
<td>Objective 1: No flashover in the kitchen before complete evacuation of occupants not intimate with the fire.</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Objective 2: No occupants subjected to critical conditions.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Objective 3: No fire spread to adjacent compartments before fire department intervention.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Objective 4: No fire spread to adjacent buildings before fire department intervention.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Objective 5: No interruption of adjacent businesses before fire department intervention.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Performance solution for Option 3: Option 3 has the same fire protection as Option 1 with an added sprinkler system. The results show that all objectives are satisfied for Option 3. This is expected since an installed sprinkler system will control the fire within the compartment of fire origin, and prevent the occurrence of flashover, hence smoke and fire spread. The required time to evacuate is higher (301 s) for this option because people respond later, as the fire does not reach flashover. The installation of sprinklers will add to the capital and maintenance costs of the fire safety systems; however, this will be offset with the low damage to building and contents. The economic analysis, however, was not done for this study.

6 CASE STUDY USING FIRECAM™

FiRECAM™ was used to assess the fire safety performance of an 8-storey court building. The existing fire protection systems in this building were being re-evaluated to see how they could be upgraded to meet the current building code requirements. The building has a typical floor area of approximately 3,100 m², with the 7th and 8th floors having smaller floor plates. The building also has two basement levels that are used for underground parking. The building does not have the required sprinkler protection, except in the basement levels and on the 7th and 8th floors. The building also does not have the required number of exit stairwells. In addition, the central core of the building has an open escalator that runs from the ground floor to the 6th floor, which allows smoke to spread easily throughout these floors in case of a fire. Figure 5 shows the layout of the stairwells. There are 4 existing corner stairwells and one centre stairwell. In the model, the single centre core stairwell was used to represent the combination of the existing centre core escalator and the stairwell. The 3 stairwells on the side of the building represent proposed new stairwells to meet the exit requirement.

One of the difficulties with this building is that it has a heavy schedule of court proceedings and therefore any upgrade work needs to be carefully planned so as to minimize the impact on these
proceedings. In addition, the building structure has asbestos insulation, which makes it difficult to retrofit a new sprinkler system.

The objective of this study was to provide an assessment of the risk-to-life reduction of upgrades to sprinkler protection, additional stairwells and/or centre core smoke control for such a court building either individually or in combination. This allows the owners and fire consultants to plan their upgrade work in stages, in case not all of the upgrade requirements can be carried out at the same time. The results of the assessment would help them to determine which requirements to do first and which can provide the highest reduction in risk without causing a major inconvenience in the use of the building. The remaining requirements could be completed later. Table 5 shows the options that were assessed, which included the code-compliant option, the current option (existing fire protection system) and six other cases of individual and combination upgrades of sprinkler protection, additional stairwells and centre core smoke control.

![Figure 5. Layout of the existing 5 stairwells (solid line) and the proposed 3 new stairwells (dotted line).](image)

<table>
<thead>
<tr>
<th>Options</th>
<th>Sprinklers</th>
<th>No. of Stairs</th>
<th>Centre Core Stairwell Pressurization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Yes</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>Current</td>
<td>No</td>
<td>5</td>
<td>No</td>
</tr>
<tr>
<td>Case 1</td>
<td>Yes</td>
<td>5</td>
<td>No</td>
</tr>
<tr>
<td>Case 2</td>
<td>No</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Case 3</td>
<td>No</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 4</td>
<td>Yes</td>
<td>8</td>
<td>No</td>
</tr>
<tr>
<td>Case 5</td>
<td>No</td>
<td>8</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 6</td>
<td>Yes</td>
<td>5</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The expected risk to life predicted for the 8 options, normalized by the Code Option for relative comparisons, is plotted in Figure 6. The Code Option is the code-compliant option, which has a relative expected risk to life value of 1.

The Current Option has a high relative risk value of 134, when compared to the Code Option. This is because the Current Option has no sprinkler protection, only 5 stairwells and a high probability of smoke spread through the centre core.

Cases 1 to 3 represent different improvements to the Current Option. Case 1 lowers the relative risk value to 13 with the installation of sprinkler protection. Case 2 lowers the relative risk value to 53 with the construction of 3 more stairwells. Case 3 lowers the relative risk value to 58 with the addition of the centre core stairwell pressurization.

Cases 4 to 6 represent further improvements to the Current Option with various combinations of Cases 1, 2, and 3. Case 4 lowers the relative risk value to 5 with the installation of sprinkler protection and the construction of 3 more stairwells. Case 5 lowers the relative risk value to 10 with the construction of 3 more stairwells and the addition of the centre core stairwell pressurization. Case 6 lowers the relative risk value to 1.
value to 6 with the installation of sprinkler protection and the addition of the centre core stairwell pressurization.

Figure 6. Relative expected risk to life values for the 8 design options for the court building.

7 SUMMARY AND CONCLUSION

To conduct performance-based fire safety designs, the fire community needs fire safety-engineering tools that will allow to evaluate designs and to determine whether they satisfy the established objectives. Two such tools are FIERA system and FiRECAM™, computer models being developed at the National Research Council of Canada. FIERA system and FiRECAM™ provide information on the safety and associated cost of candidate fire protection systems, and are expected to assist engineers and building officials in evaluating fire protection systems in buildings and in determining compliance with a set of objectives for buildings. In this study, FIERA system was used to assess different fire safety design options to determine whether they satisfy a set of user-defined objectives in a 3-storey typical building. Three different design options were considered. Two of the options did not satisfy all established objectives. One option was found to be acceptable based on the set objectives. FiRECAM™ was presented as a tool that can be used for assessing the impact of design options on life safety and for evaluating equivalency and performance-based design. In this paper, FiRECAM™ was used to show how the impact of different fire safety design options on life safety could be assessed. An 8-storey building was used to demonstrate how the model works. Based on the results of the analysis, it was shown that the designer could choose the option that provides high safety with low cost.

8 ACKNOWLEDGEMENT

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9 REFERENCES
