Effects of Fire Barriers on Building Fire Risk - A Case Study Using CUnrisk

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Abstract

CUnrisk as a comprehensive fire risk analysis model have been under active development over the past decade. Recently a Barrier Failure submodel and a Fire Spread submodel have been integrated into the CUnrisk system structure. CUnrisk can provide data of barrier failure followed by results of fire spread through the Fire Spread submodel. This paper presented a fire risk analysis case study of a six-storey apartment building of light-frame construction, aimed at showing the performance of CUnrisk and particularly the effect of wall barriers on building fire risk. The apartment building has 18 different designs of wall barriers, all of which are light frame assemblies but with different configurations. These wall barriers have different failure times under the unsuppressed fires in the apartment of fire origin, and consequently resulted in different times of fire spread to the adjacent compartments. The maps of fire spread in the unsuppressed fires at 60 minutes demonstrated good patterns and the important role of fire barriers in containing a fire. The impact of wall barrier designs on occupant risk is also discussed. Results showed that the building designed with better fire-resistive barriers could lead to lower occupant deaths, which are presented quantitatively.

Keywords: fire risk assessment; barrier failure; fire spread; life risk; occupant evacuation

1. Introduction

The performance-based fire safety concept accepted and practiced by a number of countries has allowed the construction of buildings that could not have been possible in a strictly prescriptive-code environment. To facilitate this work, some comprehensive fire risk assessment models have been developed, including FiRECAM [1] and FIERAsystem [2] in Canada, CESARE-Risk [3] in Australia, CRISP [4] in the UK and B-RISK [5] in New Zealand. These models were developed to simulate all aspects of a fire incident, such as fire growth, smoke movement and occupant evacuation, and attempted to account for the dynamic interactions among these aspects from the perspective of fire risk assessment. Indeed, this approach has its advantage over single-functionality models such as FDS [6] or evacuation models which could only simulate smoke spread or evacuation while overlook the dynamic interactions between them. All the aforementioned comprehensive fire risk analysis models have submodels to predict the fire development in the compartment of fire origin and smoke conditions in a building, using one or two zone models. They also have evacuation models to evaluate occupant safety under a fire. Most of them have an economic loss submodel to calculate fire damages. However, for the calculation of the barrier failure and fire spread, none of the models have satisfactory solutions. They either use extremely simple approaches or engineering judgement, or rely on results of external models that do not quite fit in their system structure.

CUnrisk [7] is a comprehensive fire risk analysis model developed at Carleton University in Canada. It can evaluate the overall fire risk of a building using selected fire scenarios based on the building characteristics and the available active and

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Peer-review under responsibility of the organizing committee of ICPFFPE 2015
doi:10.1016/j.proeng.2016.01.154
passive fire protection systems. It includes a system model (see Fig.1) and more than ten submodels. The system model sets up a predetermined set of procedures to coordinate all the submodels. When performing a fire risk analysis, fire scenarios are generated by the Fire Scenario submodel. For each fire scenario, building fire tenability conditions are predicted by the submodels of Fire Growth, Smoke Movement, Barrier Failure and Fire Spread, considering the intervention of active fire protection systems such as sprinklers, detectors, alarms or the fire department. Furthermore, occupant response and evacuation processes are simulated incorporating the effects of building tenability conditions on occupant movement and behaviour, and the resulting life risks are predicted. Economic losses due to fires are also calculated using the Economic Loss submodel. After addressing all the fire scenarios for a specific design, the two final output parameters, Fire Cost Expectation and Expected Risk to Life, are determined.

Some major improvements of CUrisk have been made in the last few years. Improvements have been made on the two-zone Smoke Movement submodel [8] to describe heat and mass transfer across the interface between the upper and lower layers. Modifications were also made in this submodel to consider the contribution of timber components to fire in timber constructions [9]. Most importantly, a fully integrated Barrier Failure submodel and a Fire Spread submodel were added to CUrisk. The Barrier Failure submodel [10] was developed based on the concept of component subtractive method. It can produce barrier failure probabilities in any given fire severity by taking into account the uncertainties of some factors that affect the assembly failure. The Fire Spread submodel [10, 11] is a probabilistic model based on Bayesian network approach, and can produce the time-dependent fire spread probabilities from the compartment of fire origin to any other compartment in the building during a fire scenario.

In CUrisk, the Occupant Response submodel [12] is used to predict the response of occupants in fire emergencies. The occupant response model predicts the probabilities of occupants perceiving fire signals due to direct perception, receiving fire alarms signals after the activation of local alarms, central alarm and voice alarm. The Occupant Evacuation submodel [13] uses a coarse network approach to describe a building and an individual perspective to represent occupants and then provides the data of evacuation route and time of each occupant to the Life Hazard submodel. Life risk are calculated by the Life Hazard submodel, and presented as number of deaths and injuries. The life risk of individual occupants is determined based on their egress path and the fire hazard conditions along that path. The probability of death of each occupant is a combined effect of heat, toxic gases and fire spread. The Expected Risk to Life is one of the two final decision-making parameters, defined as the expected death frequency per year per individual of a building. Besides, the Economic Loss Submodel together with the Building Cost Submodel calculate economic losses incurred for each fire scenario, based on fire conditions, economic values of contents, and damage criteria. Similar to ERL, the Fire Cost Expectation (FCE) is the other final decision-
making parameter of CUrisk. \( \text{ERL} \) and \( \text{FCE} \) can be directly used as a decision-making parameter if there is available reference data or can be compared with that of another similar, but deemed-to-satisfy code-compliant building.

In this paper, a fire risk analysis case study is conducted to demonstrate the functionality and performance of CUrisk after the recent improvements. In particular, emphasis is given to the role of the Barrier Failure submodel and the Fire Spread submodel on evaluating the occupant risk in combination with other submodels.

## 2. A case study using CUrisk

### 2.1. Design of Case Study

The upcoming National Building Code of Canada (NBCC) will allow the construction of combustible light-frame residential and office buildings up to 6 storeys. This is an increase from NBCC 2010 [14] which had a limit of four storeys for combustible construction. Accordingly, a six-storey light-frame apartment building is created for the case study. Its floor plan and dimensions are shown in Fig.2. The total floor area is 805 m\(^2\), with a floor height of 3 m. Each floor has ten 2-bedroom apartments (8 m by 8 m) with 5 of them on each side of a 40 m by 1.5 m corridor. At each end of the floor there is a common area, an elevator (concealed) and a stair room (fully open to the common area). The layouts of all the floors are identical except that two exits (2 m by 2 m) to the outside are located at the two ends of the first floor. The design of all the apartments is the same. Each apartment has a living room, a kitchen and 2 bedrooms. The partitions within all the apartment are ignored, and each apartment is considered as one compartment in the CUrisk simulation. Each apartment has a door (2 m high by 0.9 m wide) opening to the corridor and a window measuring (1.5 m high by 4.5 m wide). A door measuring 2 m high by 0.9 m wide connects the corridors and the common areas. All the doors of the apartments (to the corridors), corridors and the building entrances are set to 10% open, and all the windows are assumed to break at 300 °C.

[Fig.2 (a) Floor plan of the first storey Figure, (b) Dimensions of apartment and other spaces]

It is assumed that 4 persons occupy each apartment (2 occupants are located in each bedroom) which is the design occupant load specified by the National Building Code of Canada (NBCC) 2010 [14]. The occupants are assumed to be 50% male, 50% female, 50% adults and 50% children.
Active fire protection systems are installed in the building as per code requirements. Sprinklers are installed in all the apartments and corridors. Smoke alarms are installed in all the apartments, and smoke detectors are installed in all the corridors and stair rooms. The time of Fire Department action is divided into notification time, response time and setup time, which are set to be 30 s, 360 s, and 120 s, respectively.

2.2. Design of fire barriers

Fire barriers comprise walls, floors, doors and windows. In this case study, eighteen types of apartment wall barriers are designed and listed in Table 1. These walls are of light-frame construction and their failure behaviour is calculated by the Barrier Failure submodel. All the wood studs or steel studs are nominal 2 inch by 4 inch (38.1 mm by 88.9 mm in engineering practice) with a spacing of 400 mm o.c. The cavity is either void or filled with glass fiber or rock fiber. Type X gypsum boards of 1/2 inch (12.7 mm) or 3/8 inch (15.9 mm) are used.

To compare the impact of different wall barriers on the building fire risk, it is assumed that all wall barriers in the same building are of the same type. This leads to 18 building designs constructed with 18 types of wall barriers, respectively. All other barriers (floors, doors and windows) are the same in all the 18 building designs.

| Wall # | Studs type | Cavity filling | Gypsum board thickness (mm) | Number of layers on both sides |
|--------|------------|----------------|----------------------------|-------------------------------|
| 1      | Wood       | Void           | 12.7                       | 1                             |
| 2      | Wood       | Glass Fiber    | 12.7                       | 1                             |
| 3      | Wood       | Rock Fiber     | 12.7                       | 1                             |
| 4      | Wood       | Void           | 15.9                       | 1                             |
| 5      | Wood       | Glass Fiber    | 15.9                       | 1                             |
| 6      | Wood       | Rock Fiber     | 15.9                       | 1                             |
| 7      | Wood       | Void           | 12.7                       | 2                             |
| 8      | Wood       | Glass Fiber    | 12.7                       | 2                             |
| 9      | Wood       | Rock Fiber     | 12.7                       | 2                             |
| 10     | Steel      | Void           | 12.7                       | 1                             |
| 11     | Steel      | Glass Fiber    | 12.7                       | 1                             |
| 12     | Steel      | Rock Fiber     | 12.7                       | 1                             |
| 13     | Steel      | Void           | 15.9                       | 1                             |
| 14     | Steel      | Glass Fiber    | 15.9                       | 1                             |
| 15     | Steel      | Rock Fiber     | 15.9                       | 1                             |
| 16     | Steel      | Void           | 12.7                       | 2                             |
| 17     | Steel      | Glass Fiber    | 12.7                       | 2                             |
| 18     | Steel      | Rock Fiber     | 12.7                       | 2                             |

2.3. Design of fire scenarios

Design fires in the apartments are specified based on statistical data and engineering judgement, whereas fire scenarios in other compartments such as corridors, common areas and staircases are ignored due to extremely low fire loads in those areas that could not support sustainable fires. According to Canadian statistics [15], for family dwellings the mean value of fire load density is 500 MJ/m². The 80th and 90th percentile values are 750 MJ/m² and 825 MJ/m², respectively. The design fire load is usually chosen as a value between the 80th and 95th percentile [16]. In this study, a 90th percentile of 825 MJ/m² is chosen as the fire load density in each apartment. To be on the conservative side, a fast growth t-square fire (0.19 kW/s² [17]) is specified for the fire growth period of the design fire, and the nominal maximum heat release rate of the design fire is set to 17.6 MW. The actual size of the fully developed fire and the time of the decay phase are calculated by the Smoke Movement submodel based on the ventilation conditions of apartment and the available fire loads.
The event tree method is adopted to create fire scenarios clusters. The fundamental events that affect the fire consequences include the initiating event and some intervening events. The initiating event is the start of fire. Two fire locations and their respective occurrence probabilities are created based on statistical data. The occurrence time of the fire (daytime or nighttime) is also an important factor that affects the fire consequences especially life risk, as occupants need longer time to respond to the fire at night. The Occupant Response submodel is able to simulate the response behavior during daytime or night time. Statistical data [18] show that 20% of the fires occurred at night from 11pm to 7am when people are sleeping, and 80% occur in daytime. The intervening events include the reliability of activation of fire sprinklers, detectors and alarms, and the reliability of the Fire Department action. Sprinkler reliability is a combination of the operational probability and performance probability which is 87% based on the US statistical data [19]. Reliability of smoke detectors is 86% [20]. Fire department has a probability of 75% to arrive at the fire scene and begin firefighting in 8 minutes [21]. It should be noted that the reliability of detector and alarm systems is already considered in the Occupant Response submodel, thus is not included in the event tree. Using the event tree method, 16 fire scenarios are created as shown in Fig.3.

| Occurring Time | Fire Location | Reliability of Fire Sprinklers | Reliability of Fire Department | Fire Scenario Number | Fire Scenario Probability |
|----------------|---------------|-------------------------------|-------------------------------|----------------------|--------------------------|
| Day (0.8)      | Apt.1 (0.5)   | Y (0.87)                      | Y (0.75)                      | 1                    | 0.261                    |
|                |               |                               | N (0.25)                      | 2                    | 0.087                    |
|                |               | Y (0.75)                      | N (0.25)                      | 3                    | 0.039                    |
|                |               |                               | N (0.25)                      | 4                    | 0.013                    |
| Night (0.2)    | Apt.3 (0.5)   | Y (0.87)                      | Y (0.75)                      | 5                    | 0.261                    |
|                |               |                               | N (0.25)                      | 6                    | 0.087                    |
|                |               | Y (0.75)                      | N (0.25)                      | 7                    | 0.039                    |
|                |               |                               | N (0.25)                      | 8                    | 0.013                    |
|                | Apt.1 (0.5)   | Y (0.87)                      | Y (0.75)                      | 9                    | 0.06525                  |
|                |               |                               | N (0.25)                      | 10                   | 0.02175                  |
|                |               | Y (0.75)                      | N (0.25)                      | 11                   | 0.00975                  |
|                |               |                               | N (0.25)                      | 12                   | 0.00325                  |
|                | Apt.3 (0.5)   | Y (0.87)                      | Y (0.75)                      | 13                   | 0.06525                  |
|                |               |                               | N (0.25)                      | 14                   | 0.02175                  |
|                |               | Y (0.75)                      | N (0.25)                      | 15                   | 0.00975                  |
|                |               |                               | N (0.25)                      | 16                   | 0.00325                  |

To calculate the final two decision making parameters Expected Risk to Life and Fire Cost Expectation, the annual fire frequency, design life of the building, fire scenarios and their probabilities are needed. The Ontario (a province in Canada) statistical data shows the residential fire ignition frequency to be 2.61 × 10⁻³ per unit per year [22], therefore, the annual fire frequency of the 60-apartment building can be estimated as 0.1566 per year. The design life of the building is set to be 50 years. The simulation time for all the scenarios is 3600 s, with a time step of 2 s in simulation.

3. Results and discussion of the case study

3.1. Fire development

Fig.4 shows the fire temperature development profile in Apt.1 (see Fig.2) with or without fire suppression, computed by the Smoke Movement submodel for Scenario 1 to Scenario 4 (see Fig.3). The black solid curve is the fire temperature profile without any fire suppression in Scenario 4; the red dash curve shows the fire temperature with only Fire Department intervention in Scenario 3; the brown short dash curve demonstrates the impact of fire sprinkler activation and the blue dot curve shows the fire development under both the fire sprinkler and Fire Department intervention. The fire under no suppression indicates the fire growth, fully developed and decay periods, with a peak temperature of about 1300°C. Fire department firefighting takes effect at around 10 minutes and the fire begins to decay at around 17 minutes and drops to around 400°C at the end of the 60 minute simulation time. Under the intervention of the fire sprinkler (or together with the Fire Department operation), fire temperature only reaches up to about 180°C. The fire temperature profiles in Apt.3 in Scenario 5 to 8 are basically the same as the results in Apt.1. These fire temperature profiles are used in other CUrisk submodels to calculate the life risk and fire damages.
3.2. Barrier failure

The primary purpose of this case study is to show the effects of different fire barriers on the fire spread process. Outputs of the Barrier Failure submodel are directly used by the Fire Spread submodel to produce the probability of fire spread. The following graphs (Fig.5, Fig.6, and Fig.7) demonstrate the probability of barrier failure and fire spread for the 18 types of wall barriers shown in Table 1.

Fig.5 shows the probability of barrier failure of all the 18 wall barriers under the fire in Scenario 4. These wall barriers work as boundaries of the apartment of fire origin which is Apt.1, and thus are directly exposed to the free-growing fire (see black solid curve in Fig.4). The 18 wall barriers demonstrate different barrier failure times ranging from 23 minutes to 60 minutes. Among them, barrier 10 and Barrier 1 have the earliest failure times between 22 minutes and 25 minutes, and Barrier 10 leads to a bit earlier failure time than Barrier 1. This is followed by failure of Barrier 11, distributed around 24 to 25 minutes; and then Barrier 2, distributed between 27.5 minutes to 29.3 minutes. After that, Barrier 13 and Barrier 4 fail slightly after 30 minutes. Barrier 14 fails at around 34 minutes, and Barrier 4 (same as barrier 14 but timber frame) fails between 34 minutes to 37 minutes. Further, Barrier 7 and Barrier 16 have the same probability distribution of failure times which ranges from 51 minutes to 60 minutes. All other types of wall barriers show no sign of failure during the 60 minute simulation time, and they are unlikely to fail even if the simulation time is increased because the fire has already entered the late decay phase.

Fig.6 displays the probability of barrier failure of all the 18 wall barriers under fire in Scenario 3, and they are directly exposed to the fire in Apt.1 under the intervention of Fire Department (see red dash curve in Fig.4). Compared with the early and effective fire suppression with fire sprinklers, which suppresses the fire in its early growth phase, firefighting from the Fire Department is not able to prevent the fire going into the fully developed period. Consequently, fire is able to cause failure of four types of wall barriers, as shown in Fig.6. Two of them are Barrier 10 and Barrier 1, which fail at around 27 minutes. The other two are Barrier 13 and Barrier 4, which fail in tandem between 37 minutes and 40 minutes. All other types of wall barriers did not fail.
3.3. Fire spread

After the run of the Barrier Failure submodel, the Fire Spread submodel calculates the probability of fire spread in all compartments in the building. Fig.7 demonstrates the probability of fire spread to Apt. 2 resulting from the fire in Apt. 1 in Scenario 4. These results are a direct consequence of the barrier failure calculated by the Barrier Failure submodel as illustrated in Fig.5. The initiation times of the probability distribution of fire spread for the 18 wall barriers follow the same time sequence as the results of the barrier failure times, but occur at later times due to the fact that it takes time for the fire in Apt. 2 to be ignited and grow to a fully developed fire. The fire may continue to grow and spread to other compartments in the building, and these fire spread outputs are further processed in other submodels to estimate fire losses.

A fire initiated in a compartment can spread beyond the compartment of fire origin to adjacent compartments either on the same floor or floor above, and the worst case is that an uncontrolled fire could affect more building areas. Fig.8 (a) illustrates the eventual probability of fire spread at 60 minutes in Fire Scenario 4 where the fire initiates in Apt. 1, whereas Fig.8 (b) shows the results of Scenario 8 when Apt. 3 is the room of fire origin. Please note that in both scenarios no fire suppression is undertaken.

In both fire scenarios, the fire on the first floor spreads up to the 5th floor through external windows. Horizontally, the fire can spread to the room across the corridor by breaching the two door barriers, for example, from Apt.1 to Apt.6 in Scenario 4, from Apt.3 to Apt.8 in Scenario 8, or from Apt.11 to Apt.16, and so on. The above fire spread results are largely affected by the failure of windows and doors rather than wall barriers, thus the types of wall barrier have a small impact.

The wall barriers play a more important role in fire spread across adjacent apartments separated by them. Just as the time sequence of failure demonstrated in Fig.5 and time sequence of fire spread in Fig.7, wall Barrier 1 and Barrier 10 lead to the broadest fire spread on the floor of fire origin, including three adjacent apartments (Apt.1 to Apt.3) in Scenario 4 and five adjacent apartments (Apt. 1 to Apt.5) in Scenario 8, respectively. Similar results are found on the floors above. Lower levels of adjacent fire spreads are found with Barriers 2, 4, 5, 11, 13 and 14. Other barriers generate no adjacent fire spreads.
submodel. As a result, in the following discussion the mean parameter values of the 2000 runs are presented whenever times are longer than in daytime fires. Results show some deaths resulting from fire spread. The death predictions of fire total number of deaths, showing the earlier the wall barrier f ails, the more deaths occur. The only one exception is the

The Monte Carlo approach is adopted in the Occupant Evacuation submodel, and 2000 Monte Carlo loops are used in this case study. Correspondingly, the same number of runs are conducted for the Fire Spread submodel and the Life Hazard submodel. As a result, in the following discussion the mean parameter values of the 2000 runs are presented whenever mentioned.

Results suggest that fire spread has limited impact on occupant life risk in all the pre-defined fire scenarios and building designs. Simulation results indicate that no death is attributed to fire spread for the daytime fire scenarios (Scenario 1 to 8, see Fig.3) whereas only a small amount of deaths occurred in the night-time fire scenarios. Deaths and injuries are mainly caused by heat and toxic gases according to outputs of the Life Hazard submodel.

Fig.9(a) shows the mean occupant evacuation times of all the occupants in Scenarios 4 and the building designed with wall Barrier 1. It illustrates why fire spread fails to threaten life in the daytime fires. The occupant number in the horizontal axis is counted from the first floor to the top floor with 40 occupants on each floor. It can be found that occupants in the apartment of fire origin (Apt.1) evacuate the building at the earliest time, around 4.2 minutes on average, before the fire reaches flashover (see bottom left corner in Fig.9(a)). Apart from that, the evacuation times are basically grouped by floors, showing higher mean evacuation times in higher storeys. However, compared with occupant evacuation times, fire spread occurs much later. The first fire spread occurs from the apartment of fire origin to Apt.11, which occurs at around 20 minutes far beyond the evacuation times. Similar results are found in all other daytime fire scenarios and building designs.

During the night-time fire scenarios (Scenario 9 to 16), occupants need more time to respond to the fire, thus the evacuation times are longer than in daytime fires. Results show some deaths resulting from fire spread. The death predictions of fire Scenario 16 are shown in Fig.9(b), which is a worst-case fire scenario where no fire prevention is applied. This figure presents the total number of deaths due to fire spread when fire occurred in buildings constructed with 10 different wall barrier types. The death numbers are not integers because they are averaged from the Monte Carlo repetitions. Wall barrier types affect the total number of deaths, showing the earlier the wall barrier fails, the more deaths occur. The only one exception is the comparison between Barrier 1 and Barrier 2 but their deaths values are very close. Light Steel Frame walls lead to slightly more deaths than the Light Wood Frame counterparts. The rest of 8 wall barriers (Barrier 6, 7, 8, 9, 15, 16, 17, 18) generate
the same level of deaths as Barrier 3 and 12, thus are not included in the figure. In conclusion, the Barrier Failure submodel enables CUrisk to handle the impact of fire barrier on life risk and fire loss. It was shown that for the 6-storey apartment building fire spread contributes little to the life risk compared with heat and toxic gases. For instance, results indicate that for the building designed with wall Barrier 1 in Scenario 16, the number of deaths due to fire spread is around 0.85, whereas the total death number of deaths (due to heat, toxic gases and fire spread) is 4.9.

4. Conclusion

Fire safety engineering is an interdisciplinary area that involves the dynamic connection of relatively distant fields, such as fire dynamics, material science and human behaviour, etc. The difficulties of performance-based fire safety solutions lie in the comprehension of those fields and appropriately use them to reach the safety objectives. This is the original intention of developing comprehensive fire risk assessment models. Although there are a number of powerful models widely used in fire safety engineering applications, such as CFD models to simulate fire growth and smoke spread as well as egress models to simulate the occupant evacuation process inside a building, the weakness, however, is that the full picture of the fire incident is not pieced together. For example, in egress models smoke and fire hazard could impair occupants’ movement speed or affect their route choices. Meanwhile, occupants’ reaction could possibly change the development of fire.

Comprehensive fire risk assessment models such as CUrisk not only contain submodels of different functions but also reflect the dynamic interaction among the different submodels. Furthermore, with the recent developments, CUrisk is able to predict the failure of barriers and the resulting fire spread beyond the room of fire origin, and to further calculate the effect of barrier failure and fire spread on life safety. In order to demonstrate this, a case study was presented in this paper, which showed that different construction of wall barriers led to different barrier failure times. The application of active fire protection systems such as fire sprinkler or fire department caused reduced levels of barrier failure or no failure at all. As the direct cause of fire spread, the barrier failure results were used as a factor to calculate fire spread across the building. The results demonstrated that the different construction of wall barriers resulted in different levels of fire spread. In addition, as an integrated process, fire spread gave rise to certain level of life risk to occupants, although this consequence might be limited due to the time frame differences between time of fire spread and time of evacuation.

Through this case study it is intended to show the performance of the CUrisk as a comprehensive fire risk assessment model, more importantly to bring to attention the fact that fire incident is a complicated and dynamic process such that more researches in this matter shall be conducted.

Acknowledgements

The authors would like to thank FPInnovations and the Natural Science and Engineering Research Council of Canada for funding the development of CUrisk and this study.
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Biography

Dr. Xiao Li is an Assistant Fire Engineer in Arup Shanghai office. He recently completed his Ph.D from Carleton University in Canada under the supervision of Professor George Hadjisophocleous. His Ph.D research focused on developing submodels, in particular, barrier failure and fire spread, for the comprehensive fire risk assessment computer model CUrisk, which has an intended application in timber constructions. Xiao also conducted a series of full-scale fire tests to investigate fire performance of timber constructions, in part to support the model development. Before his Ph.D, he obtained a master’s degree in the State Key Lab. of Fire Science (SKLFS), University of Science and Technology of China (USTC).

Dr. Xiaoqian SUN is an Associate in Arup with fire safety background. He has a wide experience in applying fire engineering approach and risk based methodology to building design, and is a recognized expert in this industry. Dr. Sun holds a Ph.D degree from SKLFS, USTC.

Chin-Fai WONG is currently the leader of Arup Wuhan office and holds various professional qualifications including Chartered Engineer, Member of Chartered Building Services Engineers, Member of HK Engineers, Registered Professional Engineer, etc. Mr. Wong has extensive experience in Fire, mechanical and electrical system design and practical installation in landmark commercial buildings, industrial factories, healthcare and infrastructure projects in Hong Kong, PR China and Macau over last 23 years. He has experienced fire risk assessment, performance-based codes, CFD modeling and practical completion especially for super-high rise buildings which are more than 400m height in past ten years.

Prof. George HADJISOPHOCLEOUS holds the Industrial Research Chair in Fire Safety Engineering at Carleton University, since 2001. His research areas include the performance of building elements such as timber and steel connections in fire, fires in trains and tunnels, fire risk analysis, smoke movement, design fires and fire modelling. He holds a Ph.D. degree in Mechanical Engineering from the University of New Brunswick and he is the author of over 200 publications in the areas of fire research, tunnel fire safety, fire risk assessment, performance-based codes and CFD modelling. Dr. Hadjisophocleous is a Fellow of SFPE, the Coordinator of CIB Commission W14 on Fire, a member of NFPA, IAFSS, and a Registered Professional Engineer in the Province of Ontario. He is also the President of CHM Fire Consultants Ltd, a fire consultancy company based in Ottawa Ontario.