Impact of Open Kitchen Design in a Small Domestic Flat on Fire Safety

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Abstract: The research is mainly to study the function of the sprinklers in an open kitchen and the necessary improvement methods. In this research, it was found that sprinklers could control the hot gas temperature and radiative heat flux from the fire, but it is not enough. The ventilation and the smoke detectors are also needed to provide in open kitchens to prevent fire spread and provide early notification for residents to escape timely.

Keywords: Open kitchens, Sprinklers, Fire Dynamics Simulator

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1. Introduction

More and more housing estates have been constructed in Hong Kong and many of them adopt the design of open kitchens. It is intriguing that what technical problems an open kitchen can cause. Safety in housing is an important issue. The impacts of open kitchens in small domestic flats on residents' safety is an interesting research topic.

Fire safety among all is a critical consideration in open kitchens. Written in Fire Services standards, there are four stages of a fire. The four stages are respectively (i) germination, (ii) growth, (iii) full development, and (iv) decay. It is evident that the risk of death increases if people are not able to leave the building-on-fire within the specified time, especially in small residential units.

Additional protection for open kitchens is required and a sprinkler head must be critically added in an open kitchen. The design of an open kitchen normally connects to that of the living room. This means that the fire will spread quickly to the whole house. This research investigates whether the installation of a sprinkler head can minimize such an impact or not.

2. Literature review

From 1999 to 2002, in the US, there were almost 125,500 families that had happened fires in the kitchens every year [1,2]. Among them, the confined cooking fires have resulted in the death of 460 people in total every year as well. Although there was only 9 percent of fires that have exceeded the scope of the kitchens, 70 percent of death was caused by fires in the kitchens. It has given the warning signal to the residents of flats with open kitchens. The fire officers have summarized their own experience of firefighting, and they suggested that it is necessary and effective to install a single sprinkler to control the kitchen fires and in a better way.

People now can use electric induction cookers for cooking fried foods. Therefore, the research of the experiments of cooking oil fires should be reviewed. According to the experiential expressions of the reports and documents, the researchers will analyze the possibilities of the onset of flashover. Within the small-sized residential units, about the firing behaviors of the combustibles, it is suggested burning something with the high thermal radiation heat flux. The design of open kitchens has provided enough air for firing and there are no fire-resisting walls that hinder heat [2]. In addition to that, air pumping will provide a higher air flow rate, which will definitely result in the continued firing of the objects that can be easily burned.

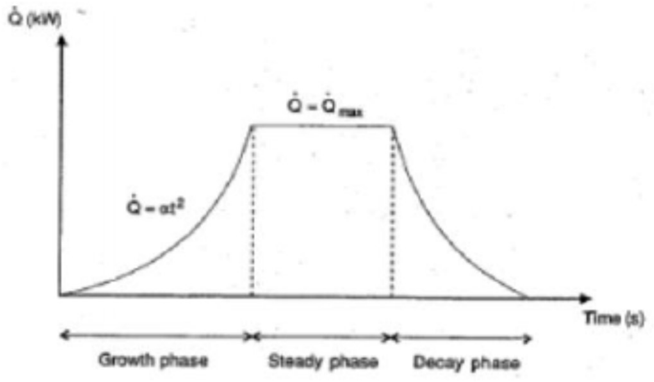
Fire Dynamics Simulator (FDS) is a computational simulation of fire development. When the data is input into FDS, the model of a fire and the results of its development will be obtained. The information that is needed for analysis, such as CO concentration, smoke layer, temperature and heat release rate, is therefore available. Then, it is needed to study the relevant fire protection regulations to investigate whether they are sufficient or not on the kitchen supervision. Two situations will be simulated – one is with sufficient sprinklers in an open kitchen, and the other one is without any sprinkler.

The sprinkler system to deal with this situation includes a water supply system that can be connected to a heating device through a pipe. The device automatically detects a fire, triggers an alarm, and triggers a mechanism to deliver water to the scene of the fire. In this way, the fire can be put out or contained before the fire brigade arrives [3].

Sprinklers in automatic sprinkler systems provide continuous fire protection with an automatic detection and fire extinguishing function. Its nozzle is a heat-sensitive device. In order for the sprinklers to cover the entire reserve, sprinklers must be placed at prescribed intervals, especially in open kitchens where the sprinklers must cover the stove and associated areas [3]. In most cases, though, only the kitchen equipment is above the fireworks. The rate of discharge of water is designed according to the fire load due to the fuel content in the protected premises and must meet the requirements of the Fire Services Department [4,5]. When the nozzle bursts, the water flowing through the nozzle triggers the device to set off an alarm. Alternatively, through a safety office or other control center, the system can be set up as an electrical alarm system operated by a pressure or flow switch.

In real fires, the rate of fire spread increases throughout the growth phase. A faster way to describe the accelerated growth is to assume that the rate of energy release increases with the square of time. In other words, when the square of time is multiplied by a coefficient of alpha, it can simulate different growth speeds. The energy release rate as a function of time can be shown as $2\ Q = \alpha\ t$, where alpha is a growth factor (usually in kW/second square (kW/s squared)), t is the established ignition timing with the unit in seconds.

The rate of growth shown by different objects correlates strongly with this relationship, but only at the time of fire and after the fire has started to spread. The starting time is denoted by T0. The starting point of the starting time depends on the goods in question and how it is ignited, usually starting from the moment of ignition until a large amount of energy is released during combustion. The example in Figure 1 is about the fastest way to design a fire curve. The curve is divided into areas of growth and areas of decline [6]. It also shows the start time t0 for each test. Figure 1 provides an example of the test, illustrating how to fit experimental data to obtain growth rate factor α. Automatic fire protection systems, such as sprinklers, control the fire during the stabilization phase and then extinguish the fire during the decay phase [6].



Simple the Fire Curve

Figure 1. Data of growth rate factor α in a large number of furniture calorimeter tests.

According to the UK Ministry of Construction, in “2011 Building Fire Safety Code G Provisions”, if the smoke height is 2 m, the radiation intensity is 2.5 kW/m^2, and the temperature of smoke is less than 60°C, then the CO emission (toxicity) is less than 1000 ppm.

3. Methodology

In order to achieve the objectives of this research, i.e. (i) to investigate the impacts of the fire happening without any sprinkler head and (ii) to investigate whether a sprinkler is necessary for an open kitchen, two situations would be simulated by Fire Dynamics Simulator. Case One is an open kitchen without any sprinkler head in a small domestic flat to address objective (i), and Case Two is an open kitchen having sprinkler protection in a small domestic flat to address objective (ii).

It is required to input the room and other relevant information into Fire Dynamics Simulator (FDS). The required information is shown below.

Methodology for addressing objective (i): to investigate the impact of the fire happening without any sprinkler head:

An apartment with an open kitchen of size 6 m (L) x 5.02 m (W) x 3 m (H) was created in FDS.

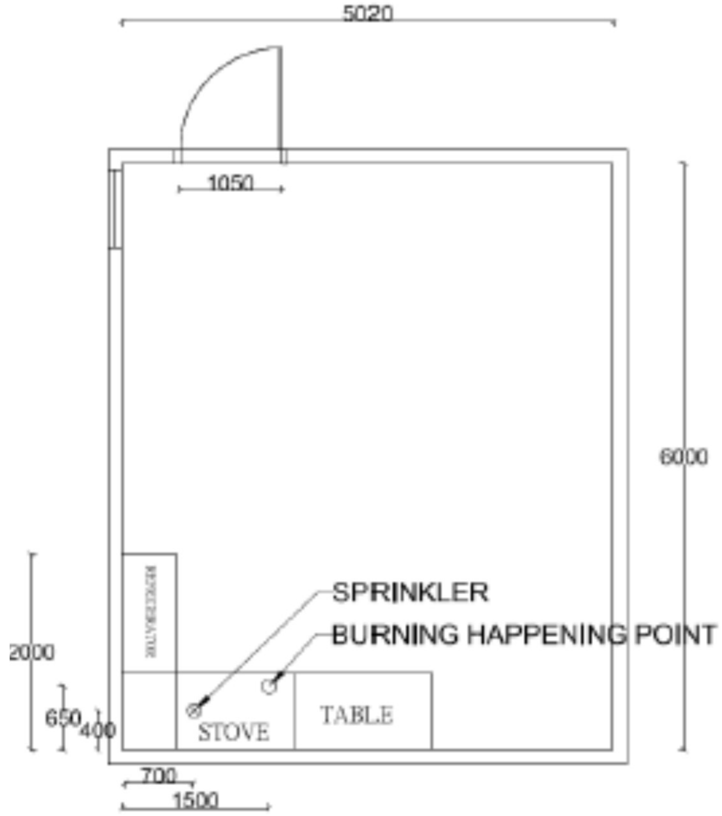


Figure 2. Layout plan of the open kitchen in a small domestic flat

Simulation time: It is assumed that the fireman will arrive within 10 minutes. Thus, smoke and fire will be developed in these 600 seconds.

Basic information: The ambient temperature is 25°C. The open kitchen does not have an independent window or ventilation in this simulation.

Meshing description: The size of a small domestic flat is about 30 m^2 or 322 ft^2. In this simulation, the room area is 324 ft^2 and the ceiling height is 3 m as the basic room dimension.

Material: The ceiling, walls and floor are made of concrete. All solid boundaries are assumed to be 200 mm concrete. Assuming specific heat: 1 J/K ; conductivity: 1.13 W/m K ; density: 2000 kg/m^3

Fire Source: Assuming the fire source is the stove. The size is 0.64 m (L) x 0.78 m (W) x 0.9m (H) and the location of the stove is shown in the layout plan in Figure 2.

Carbon monoxide is released when the fire source is burning. CO concertation and the element of fire bed are needed to be considered. The element of the stove is $C_6H_{10}O_5N_1$.

Methodology for addressing objective (ii): to investigate whether a sprinkler is necessary for an open kitchen:

All the data input to FDS is similar to that for addressing objective (i). The big difference is that a sprinkler head would be added to the open kitchen in order to protect property. The sprinkler is of the quick response type and the activation temperature is 68.33 °C. The sprinkler location is within two meters of the stove and covers the whole open kitchen area.

4. Data Collection

4.1. Simulation results of Fire Dynamics Simulator

Simulating fire happening - Sprinkler head cover (by Fire Dynamics Simulator software). Figure 3 shows that the sprinkler head is operating after the fire happening at the 78th second. Figure 4 shows that smoke has been spread all over the domestic flat.

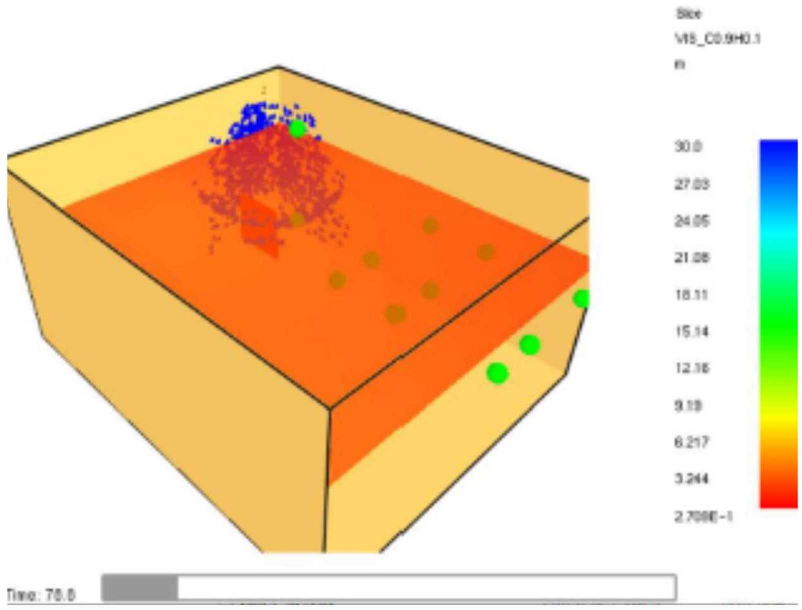


Figure 3. The sprinkler head is operating after the fire happening at the 78th second

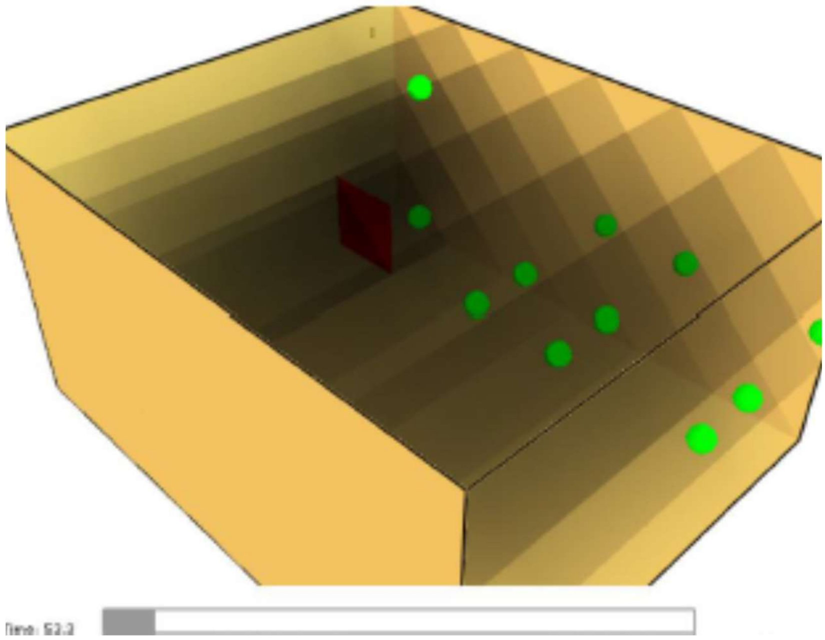


Figure 4 Smoke spread to the whole domestic flat

Figures 5 to 8 show the FDS results for addressing objective (i).

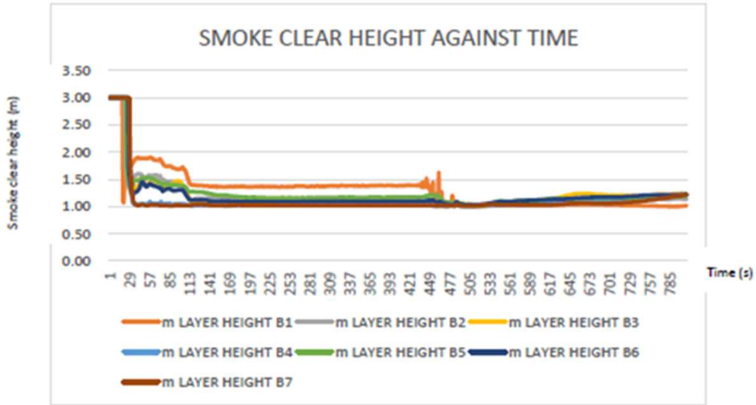


Figure 5. Smoke clear height tends to become less along the time (Case One)

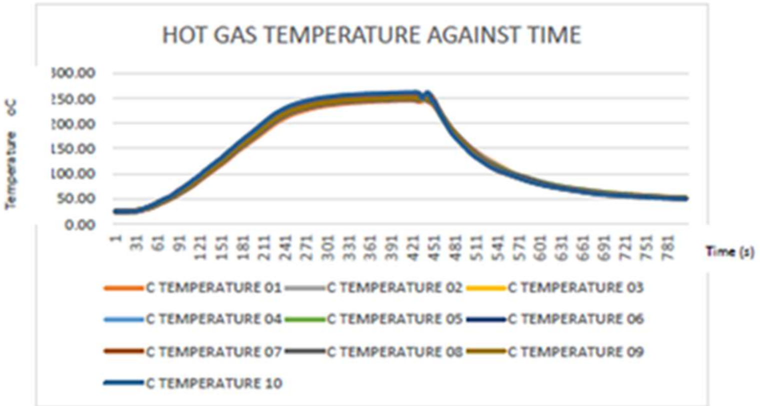


Figure 6. Hot gas temperature developed to the highest temperature and then it tends to reduce along the time (Case One)

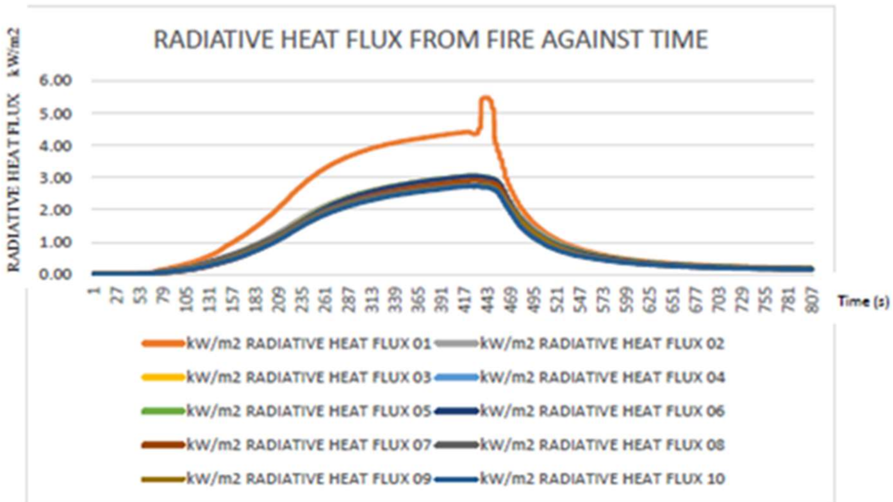


Figure 7. Radiative heat flus developed to the highest and then it tends to reduce against time (Case One)

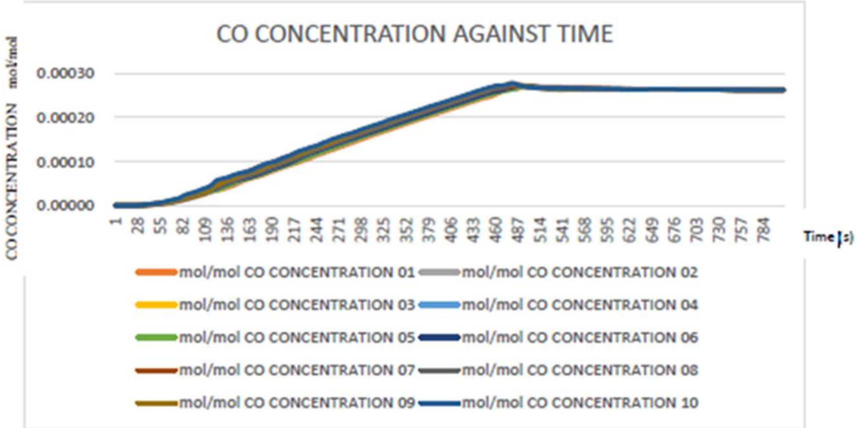


Figure 8. CO concentration tends to attain the highest after some time and then there is no change (Case One)

Figures 9 to 12 show the FDS results for addressing objective (ii).

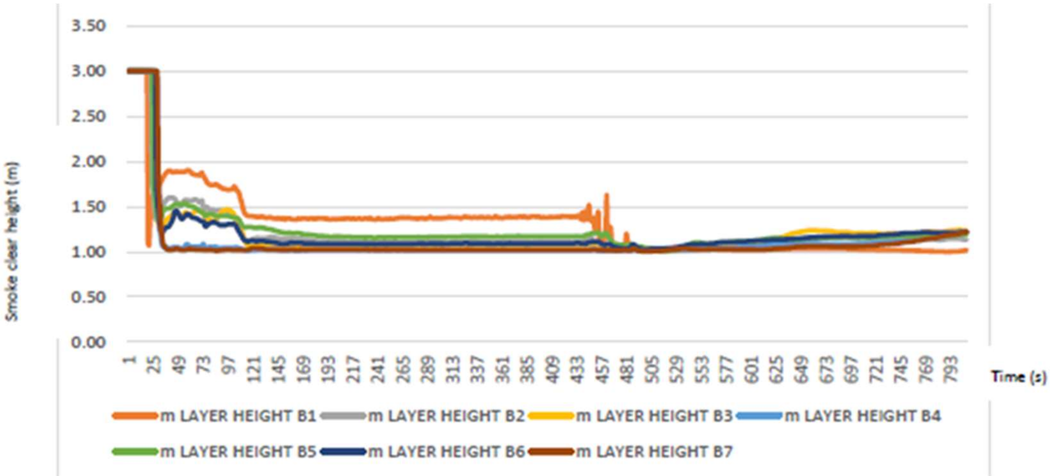


Figure 9. Smoke clear height tends to become less along the time (Case Two)

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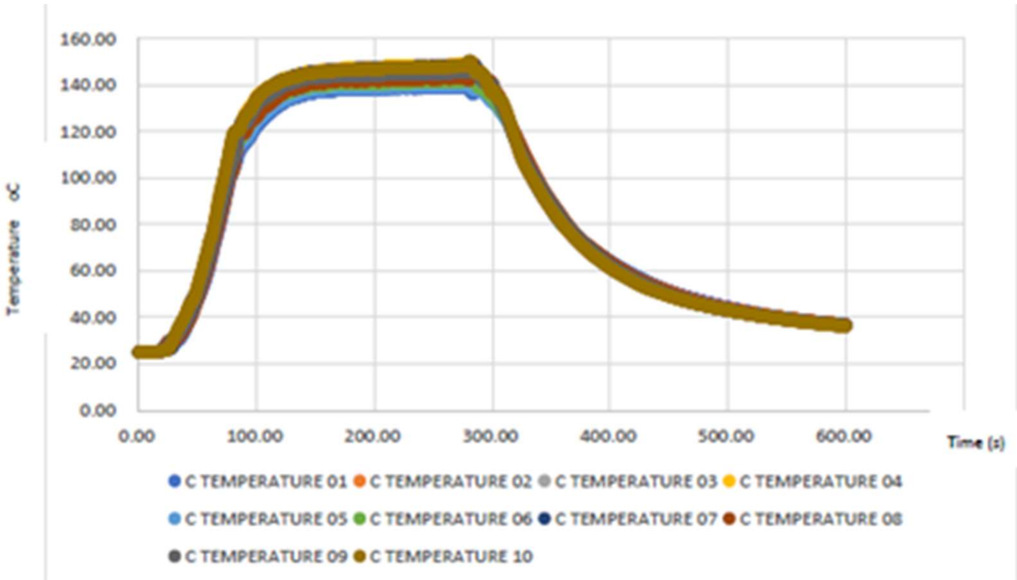

Figure 10. Hot gas temperature developed to the highest temperature and then it tends to reduce along the time (Case Two)

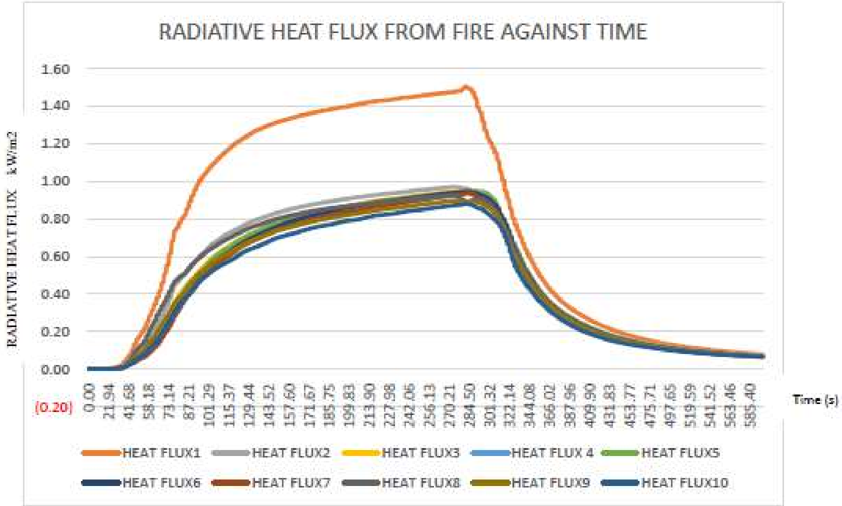

Figure 11 Radiative heat flus developed to the highest and then it tends to reduce against time (Case Two)

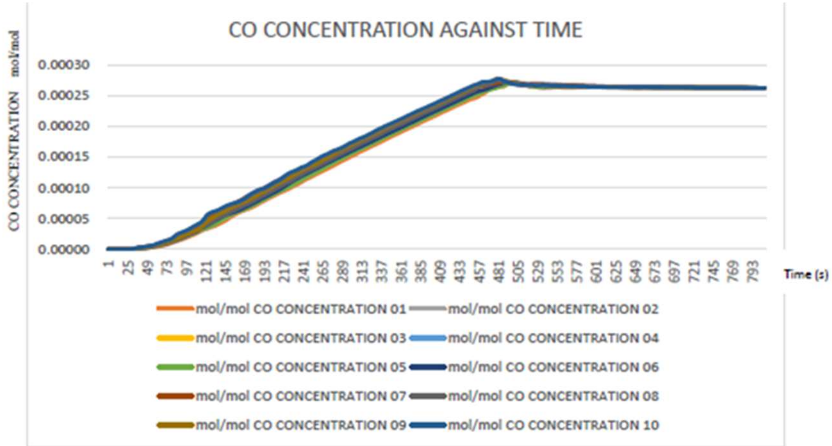

Figure 12. CO concentration tends to attain the highest after some time and then there is no change (Case Two)

5. Discussion

Radiative Heat Flux

a) Development Time

The development time of Case One is longer than that of Case Two. The growth phase and the steady phase of Case One are 235 seconds and 234 seconds respectively. The growth phase and the steady phase of Case Two are 155 seconds and 171 seconds respectively.

b) Average Radiative heat flux

The average radiative heat flux of Case One is larger than that of Case Two in the growth and steady stage. Case One does not fulfil the government's regulations (>2.5 kW/m^2) in 290 to 469 seconds.

The difference between Cases One and Two is the existence of a sprinkler head. It is believed that the sprinkler could reduce the radiative heat flux from the fire and speed up the extinguishing time. Therefore, comparing the radiative heat flux and the development time of fire between these two cases, it could be easier to handle the fire in Case Two. Case Two could control the fire more effectively. The reason is that there is a sprinkler head that can release in Case Two.

Water to cool down the fire

Table 1. Comparing the differences between Case One and Case Two in terms of radiative heat flux

	Fire happening without any sprinkler head – Case One		A sprinkler is provided for the open kitchen – Case Two	
	Time (s)	Average Radiative heat flux (kW/m^2)	Time (s)	Average Radiative heat flux (kW/m^2)
Growth Phase	0 – 235	0 – 1.5	0 – 115	0 – 0.7
Steady phase	235 – 469	1.5 – 3	115 – 286	0.7 – 0.95
Decay Phase	469 – 600	3 – ~0	286 - 600s	0.95 – ~0
Over 2.5 kW/m^2	290 – 469	>2.5 kW/m^2	/	/

CO Concentration

CO Concentration of the two cases is same. The CO concentration of two cases do not exceed that required by the government on CO Concentration, i.e. 1000 ppm (0.001). The reason is that the fire bed is the stove and it is not like highly volatile compounds to release lots of co concentration. Another reason is that lots of equipment in an open kitchen, such as a refrigerator, an oven and an exhaust fan, are still not be put into the FDS.

Table 2. Time and CO concentration of the highest point

	Highest Point
Time	483 s*
CO concentration	0.00028 mol/mol (280 ppm)

* Considering the most appearing value of the point that reached 1 meter of smoke clear height

Smoke Clear Height

Smoke clear heights of Cases One and Two are the same. A major reason is that in the simulation the open kitchen of a small domestic flat is not provided without any window or ventilation. The smoke clear height only has two meters at 30 seconds and then tends to be only one meter. It means that people are allowed to escape in only 30 seconds. The reason is that the natural ventilation, a range hood and an exhaust fan are not input into FDS is that the equipment would affect the performance of smoke clear height.

Table 3. Time and smoke clear height of the highest point

	Highest Point
Time	461 s
Smoke clear height	1m

Hot Gas Temperature

The average hot gas temperature in Case One is larger than that in Case Two. The hot gas temperature of Case One reaches to the highest temperature at 256 degree Celsius. Oppositely, the hot gas temperature of Case Two reaches to the highest temperature at 150 degree Celsius. The growth phase and steady phase of Case Two is shorter than those of Case One even though both cases exceed government standards of hot gas temperature (>60 degree Celsius). However, it is significantly faster to control the temperature in Case Two.

Table 4. Comparing the differences of Case One and Case Two in terms of hot gas temperature

	Fire happening without any sprinkler head – Case One		A sprinkler is provided for the open kitchen – Case Two	
	Time (s)	Average Hot Gas Temperature (℃)	Time (s)	Average Hot Gas Temperature (℃)
Growth Phase	0 – 235	25 – 215	0 – 115	25 – 140
Steady phase	235 – 469	215 – 256	115 – 286	140 – 150
Decay Phase	469 – 600	256 – 50	286 – 600	150 – 38
Over 60 ℃	91 – 600	>60 ℃	58 – 400	>60

6. Potential methods to improve fire protection

Ventilation is a fire protection method and is a demand for the open kitchen in a small domestic flat. It is because domestic flats, which adopt the open kitchen design, are generally small and the ceiling is not high. Smoke will be produced when the fire is happening and it is fast to occupy the breath zone. The smoke layer would significantly reduce the visibility and breathable air so it would hamper the residents to escape to safe areas. Moreover, hot smoke would speed up the flashover time happening. Thus, ventilation is a critical factor of fire protection and saving life in the open kitchen. Furthermore, a smoke detector is another fire protection method. The smoke detector would be activated by smoke. It means that the smoke in early fire stage would indicate the residents to escape when the fire is in the growth phase.

7. Conclusion

The fire happening has a great impact on the open kitchen. This research project helps people understand the importance of sprinkler heads for open kitchens. In addition to sprinkler heads, more fire prevention measures can also be provided for people to achieve the goal of a safe living environment.

8. References

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