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Impact of Canopies on Fire Spread in Pedestrian Streets

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Abstract

In order to provide a better shopping experience, canopies are commonly installed in outdoor pedestrian streets. However, the installation of canopies could restrict the smoke extraction if a fire took place in the street, and further increase the fire spread risk between the buildings along the street. This paper numerically studied the impact of canopies on a fire in outdoor pedestrian streets. Results show that while there is an opening at the center of the canopy, it would have little effect on fire spread within the street. When a fire occurred in the street, through a certain thickness of smoke layer is formed near the canopy, the gas temperature underneath it kept relatively low, which doesn't pose a threat to the human beings in the street and the steel structure of the canopy itself. While a fire occurred at a shop nearby the street, its radiation heat flux to adjacent buildings on the other side of the pedestrian street various with the distance of the two buildings. In this situation, the width of pedestrian streets is the main factor affecting the fire spread in it.

Keywords

Fire Protection Design; Heat Flux; Numerical Simulation.

1. Introduction

A pedestrian street is a shopping plaza or area concentrating abundant stores, which provided pleasant experience for the customers. Modern pedestrian streets are rich in functions, occupying a large area and having a large fire load. Once a fire occurs, the fire might quickly spread between the buildings along the two side of the street. People in buildings on both sides of the pedestrian street need to be evacuated using the pedestrian street. Therefore, the fire safety design of the pedestrian street is the key factor of the whole shopping area.

Previous studies have carried out a lot of research on fire smoke spread and the controlling methods in pedestrian streets. However, most research has focused on mechanical smoke extraction of indoor pedestrian streets, and less consideration has been given to pedestrian streets with semi-open roofs. Zhang studied the smoke control of indoor pedestrian streets based on a large commercial complex, and found that mechanical exhaust has higher efficiency than natural smoke venting in pedestrian street. Han demonstrate the smoking exhausting effectiveness of a typical indoor pedestrian street by comparing the Available Safety Evacuation Time (ASET) and Required Safety Evacuation Time (RSET) through numerical simulations.

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took place in the street, and further increase the fire spread risk between the buildings along the street. The fire protection design requirement of a pedestrian street with canopies are not clear in the current fire code in China. More attentions should be given to these special pedestrian streets. By numerical simulation methods, this paper studies the impact of canopies on the fire spread in pedestrian streets. The simulation results of gas temperature near the canopies and heat flux on both sides of the pedestrian street will be presented to analyze its fire safety.

2. Simulation setup

2.1 Introduction of FDS

Fire dynamics simulator (FDS) is used as the simulation tool in this study. FDS is a computational fluid dynamics (CFD) software for handling fire-driven fluid flow. Solving the Navier–Stokes equation through large eddy simulation to calculate low-speed thermally-driven flow. The solution is applied to the basic conservation equations [1,2,3,4,5,6].

Continuity Equation：

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \boldsymbol{u} = 0 \tag{1}$$

Momentum Conservation Equation:

$$\frac{\partial (\rho \boldsymbol{u})}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} + \nabla P = \rho g + \boldsymbol{f} + \nabla \cdot \boldsymbol{\tau} \tag{2}$$

Energy Conservation Equation

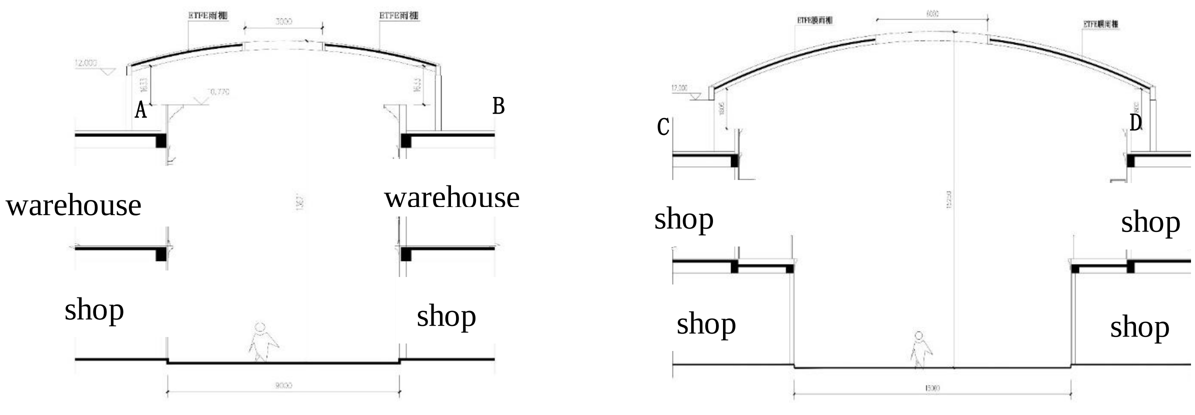
$$\frac{\partial (\rho h)}{\partial t} + \nabla \cdot \rho h \boldsymbol{u} = \frac{\partial P}{\partial t} + u \cdot \nabla P + \dot{q}_r - \nabla \cdot \dot{q} + \phi \tag{3}$$

Component Equation

$$\frac{\partial (\rho Y_i)}{\partial t} + \nabla \cdot \rho Y_i \boldsymbol{u} = \nabla \cdot \rho D_i \nabla Y_i + \dot{m}_i''' \tag{4}$$

2.2 Numerical model

Two numerical models of pedestrian streets are learnt in this study. Canopies are set above the pedestrian street as shown in Fig.1. In Model I, the width of the street is 9m, the height of Building A and B on both sides are 9.55m, and the height of the canopies are 12m. The gap between the two canopies is 3m(Fig.1(a)). In Model II, the width of the street is 15m, while the Building C and D are 9.55m in height. The highest height of the canopies are 12m, and there is also a 6m gap at the center of the canopy.



(a) Model I (b) Model II

Figure 1. Overview of pedestrian streets

In reference to the recommendation of the value D^*/δ_x provided in FDS user's guide[7], and consider the calculation speed of the simulation, the grid size is set as 0.5m(L) × 0.5m(W) × 0.5m(H). The total simulation time is 3000s.

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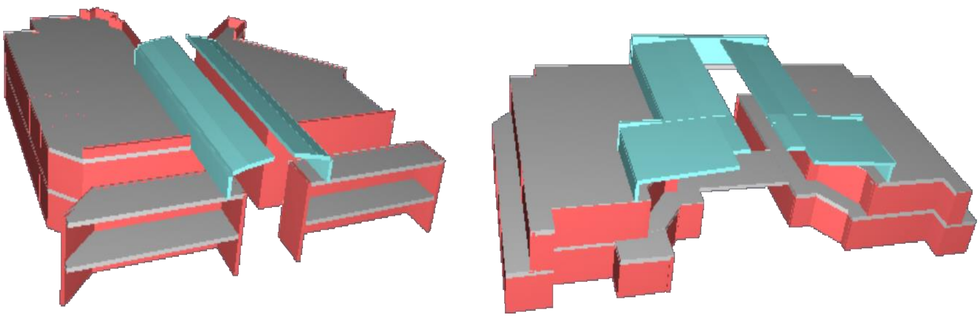

(a) model I (b) model II

Figure 2. Numerical simulation model

2.3 Fire protection design

While a fire took place, the heat release rate does not reach the maximum heat release rate immediately after igniting. Before the fire grows to the steady-state phase, there will be a growing process for most of the fires. The fire growth is considered to increase by the square of time. The relationship between the heat release rate and time is shown in equation (5)

$$\dot{Q} = \alpha t^2 \tag{5}$$

$\dot{Q}$ denotes the heat release rate, given in kW, t is the time, given in s, and, α is the growth factor of the fire.

Both store fire and warehouse fire are considered in the simulations. According to the technical standard for smoke management systems in buildings of China, different HRRs of the fires are set as Table 1. Considering the normal operation and failure of the fire extinguishing system, three worst scenarios were conducted.

Table 1 Numerical simulation details.

Case	Fire location	Fuel	Growth rate	HRR (kW)
1	Middle of class I street	Temporary fuel	Fast	6.0
2	Second floor warehouse of building A in Model I street	Commodity	Super- fast	20.0
3	Second floor shop of building C in Model II street	Commodity	Super- fast	10.0

3. Results and discussion

3.1 The smoke spread

The priority fire protection object of a commercial building is to secure the safety of evacuation personnel. The pedestrian street must be visible enough during evacuation. It is important to know how the smoke moves. A phenomenon of the smoke spread in the steady-state phase can be seen in Fig.3. It was observed that most of the smoke spread outwards through the gap of canopy, and the smoke layer beneath canopies is thin. This is possible because the gap area accounts for 30% of the pedestrian street area in case 1 and case 2, and the gap area accounts for 40% of the pedestrian street area in case 3, which is large enough for smoke to be exhausted to prevent it from moving downwards. In summary, though the smoke layer is formed near canopy, it can still keep the height of the smoke layer above the highest level in outdoor pedestrian streets, which does not affect the safe evacuation of pedestrians.

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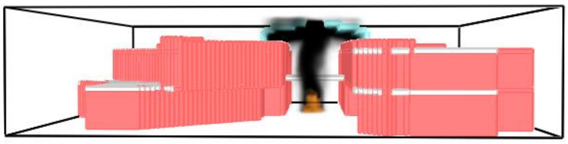
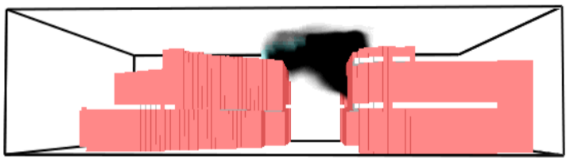
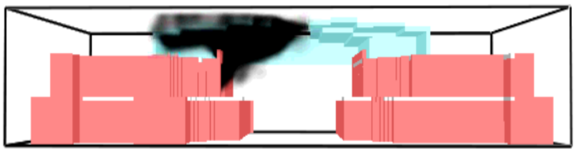


(a) case1



(b) case2



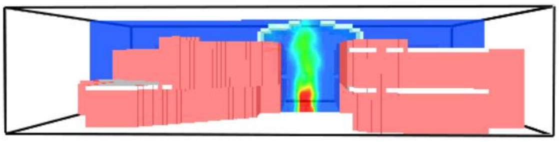
(c) case 3

Figure.3 Smoke spread in different cases

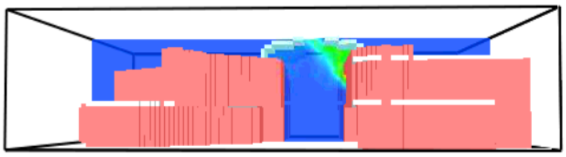
3.2 Gas temperature underneath the canopy

It is crucial for the canopy above pedestrians to maintain complete structural integrity during personal evacuation and firefighting rescue. The canopy structure is generally composed of steel pipe trusses and plates. Since high smoke temperature may cause the failure of the canopy structure to collapse in fire, the distribution of gas temperature underneath the canopy is significantly important. It was found that steel failure occur when its temperature exceeds the critical value. Base on previous study, the failure for canopy structure is considered when the gas temperature underneath the canopy exceeds 280℃ in this paper [8,9,10,11].

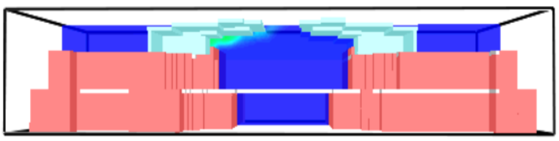
The gas temperature underneath the canopy in the steady-state phase are shown in Fig.4. The highest gas temperature locates right above the fire, with the value of 103℃ in case 1(Fig.4(a)). The maximum gas temperatures underneath the canopy are even higher in case 2 and case 3(Fig.4(b), Fig.4(c)), which are approximately 150℃ and 121℃ respectively. The maximum gas temperatures underneath the canopy are well below 280℃ in these cases. Then, it can be concluded that the gas temperature underneath canopy kept relatively low, which doesn't pose a threat to the steel structure of the canopy, and it is not enough to cause the failure of the canopy steel structure.



(a) case 1



(b) case 2



(c) case 3

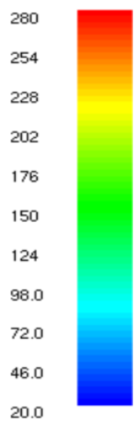


Figure.4 Ambient temperature of canopies steel structure

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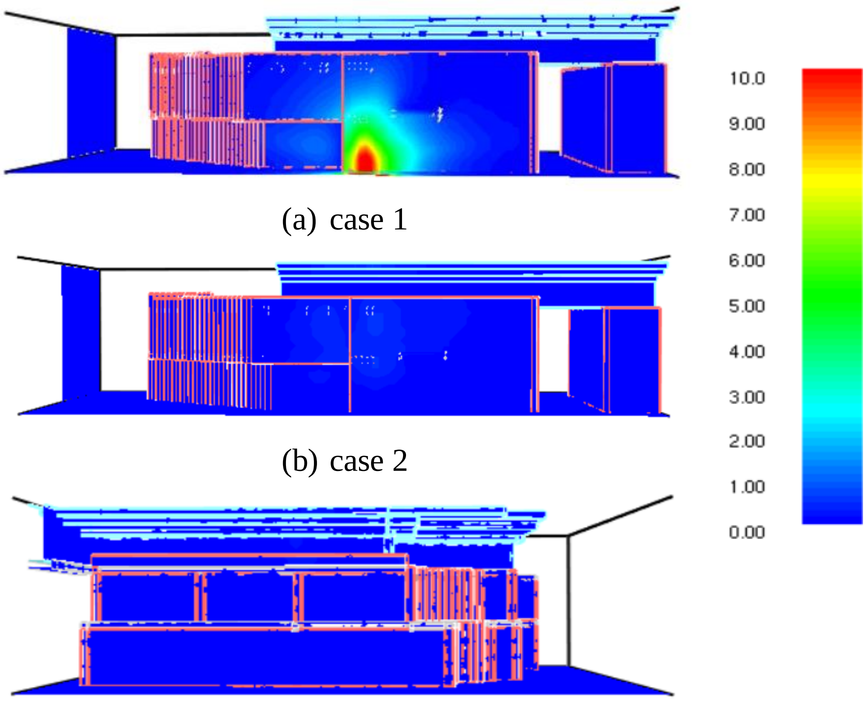
3.3 Distribution of heat flux

The radiation heat transfer is another important parameter while estimating the fire spread possibility between the buildings along the pedestrian. When heat is transfer through radiation, the radiant object can be ignited when the heat flux reaches the threshold. According to NFPA, the ignition threshold of most materials, such as light curtains and newspaper, are 10kW/m^2. This study conservatively regards this value as the limiting heat flux rate.

As shown in Fig.5, the maximum surface heat flux on the adjacent building exceeds 10 kW/m^2 in case 1(Fig.5(a)), while it is much smaller in case 2 and case 3 (Fig.5(b),Fig.5(c)). The heat flux is the function of heat release rate and radiation distance. The distance between the fire source and the Building A and B is 4.5m in case 1, and the distance are 9m and 13m in case 2 and case 3. Although the heat release rate of the fire in case 1 is smaller than case 2 and case 3, the heat flux is much higher in case 1. As a consequence, while a fire occurred at a shop nearby the street, the canopy has little influence on radiation heat flux of buildings. The radiation heat flux to adjacent buildings is significantly affected by the distance between the fire and the building rather than the heat release rate of fire source. When a fire took place in a shop along the pedestrian, the width of the streets is the main factor affecting the fire spread risk between the buildings facing each other.



(a) case 1

(b) case 2

(c) case 3

Figure.5 Heat flux distribution of adjacent buildings

4. Conclusion

Based on the numerical simulation results, when the opening area reaches 30%, the canopy has little effect on the fire spread within the street. Through a certain thickness of smoke layer is formed underneath the canopy, the gas temperature around it kept relatively low, which doesn't pose a threat to evacuation persons and the steel structure of the canopy itself in fires. While a fire occurred at a shop nearby the street, its radiation heat flux to adjacent buildings on the other side of the pedestrian street various with the distance of the two buildings. In this situation, the width of pedestrian streets is the main factor affecting the fire spread in it.

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