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КОМБИНИРОВАНИЕ ОГНЕСТОЙКИХ КОНСТРУКЦИЙ ДЛЯ ПРЕДОТВРАЩЕНИЯ ВЕРТИКАЛЬНОГО РАСПРОСТРАНЕНИЯ ПОЖАРА ПО ФАСАДУ ЗДАНИЯ

Фу Джиаджа, доктор
тел. +86-18610101591, fujj0113@163.com

Юан Хонгенг, профессор
тел. +86-18610171088, yuanhongyong@mail.tsinghua.edu.cn

Чен Джиангуо, доцент
тел. +86-13683509336, chenjianguo@mail.tsinghua.edu.cn

Отдел инженерной физики, Институт Исследований Общественной Безопасности,
Университет Цинхуа, Пекин, Китай, 100084

Жанг Джиджан, главный инженер
тел. +86-15120080019, cabrzjy@163.com

Научно-исследовательский институт пожарной безопасности зданий,
Академия наук по строительству Китая. Бэй Сан Хуан Данг Лу, 30, Пекин, Китай

Предложена комбинация противопожарных козырьков и межоконных стен, позволяющая предотвратить вертикальное распространение пожара через окно по фасаду здания. Моделирование полномасштабного здания с различными сочетаниями противопожарных конструкций и пожарной нагрузки проводилось в программной оболочке «Моделирование Динамики Пожара» (FDS). Показано, что если высота простенка между вышележащим и нижележащим окном, либо длина противопожарного козырька не отвечают требованиям строительных норм в части предотвращения развития пожара, то увеличение огнестойкости остекления обеспечит требуемые параметры пожарной безопасности фасадов. Результаты исследований позволяют произвести техническую оценку мероприятий по предотвращению пожара, а также пересмотреть действующие строительные нормы в области противопожарной защиты Китая.

Ключевые слова: пожар в здании, оконное пламя, фасад здания, противопожарная конструкция, противопожарный козырек, межоконный простенок.

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THE COMBINATION SCHEME OF FIREPROOF CONSTRUCTION TO INHIBIT THE VERTICAL SPREAD OF BUILDING FACADE OUTFLOW PLUME

Fu J.J., Yuan H.Y., Chen J.G., Zhang J.Y.

Purpose. This paper is devoted to propose the combination scheme of the fire canopy and the wall between the windows to inhibit the vertical spread of building facade outflow plume.

*Methods.*The full-scale building with the different size of fire protection constructions were simulated by FDS software under various fire sources.

Findings. When the window glass is made of 6mm thick toughened glass and the dimensionless overflow heat release rate $0 < Q_{ex}^{*} < 1{,}3$, the effect of the combination scheme in suppressing the vertical spread of outflow plume is the same.

Application field of research. The research results can provide technical support for the assessment of fire prevention, and revise the existing code for building fire protection design in China.

Conclusions. When the height of the wall between the upper and lower window or the length of the fire canopy does not meet the requirements of the code for fire protection design, we can set both at the same time, or improve the window glass fire rating to achieve the building facade fire design requirements.

Keywords: building fire, window outflow plume, building facade, fire protection construction, fire canopy, wall between windows.

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Introduction. For a fully developed under-ventilated compartment fire, the hot gases and smokes with flame eject from the facade broken window that caused by hot pressing and high temperature radiation. Thus, the special phenomenon of flame ejecting behavior has been formed. The hot gases and smokes with flame spread to upper floors under the effect of buoyancy, and burst the upper floors glass, leading to further spread of the fire to adjacent floors. In this case, the three-dimensional building fire spread is finally developed.

It is very necessary to inhibit the vertical fire spread and avoid the formation of three-dimensional fire, depending on the fireproof construction itself, not only improving the fire-resistant level of the building facade. Under the different combination scheme of fireproof construction, the temperature distribution of combustion chamber and building facade and heat transfer characteristics (such as heat radiation and heat convection, etc.) are different.

Extensive investigations have been addressed on such building facade outflow plume behavior under the restriction of the fire canopy and the wall between windows, on which the characteristic parameters and regulations are focused, including temperature profile [1-2], heat radiation intensity [3-4], heat flux profile [5-6] as well as flame shape and dimensions [7-8]. However, former investigation paid little attention to how to inhibit the outflow plume spreading speed and reduce the danger by using external fireproof construction. For the fireproof construction, the fire canopy located between the upper and lower windows and the wall between windows are an effective way to suppress the outflow plume vertical spread by experimental and simulation test [9-12]. Darryl Weinert [9] conducted a numerical simulation study and found that when the height of wall between windows is 1m, and the length of fire canopy is 0,3 m, 0,6 m and 1 m, the temperature of building facade is reduced 50, 60 and 85 %, respectively than without the fire canopy. An experimental study was done using a 1/7 scale model of seven stories high-rise apartment building by Suzuki [10]. He found that temperature in the fire room with horizontal projection was higher than those without horizontal projection. John H., Mammoser and Francine Battaglia [11] studied the barrier effect of the balcony on overflow plume of building facades by numerical simulation. By comparing with the results of similar experiments, it is shown that the numerical simulation of scaled model can be used to study the characteristics of window overflow plume under the construction of the balcony. Zongcun Wang [12] proposed the fire protection design requirements of the fire canopy and the wall between windows through the real fire simulation experiment and numerical simulation research, but he didn't propose a correspondence between the fire canopy and the wall between windows.

The requirement of the value of the length of the fire canopy and the height of the wall between windows is limited in code for fire protection design of China [13-14], and the combination of them isn't specify allowed to meet the requirement of fire protection. For example, «Residential building codes» (GB 50368-2005) [14] section 9.4.1: the height of the wall between adjacent suite window should not be less than 0,8 m or the length of the fire canopy should not be less than 0,5 m and the fire resistance limit of that should not less than 1,00 *h* and which length should not be less than the width of the window. Therefore, the requirements of the fire canopy and the wall between widows in the codes are too rigid, which is not conducive to large number of practical projects in the promotion and application. In order to provide direct guidance for fire fighters, this paper proposes a permissible combination scheme for the fire canopy and the wall between windows under different fire loads based on the FDS (Fire Dynamics Simulator) numerical simulation.

Simulation information. The simulation model (see Figure 1) was full size residential building with 4 layers and having dimensions 4 m (W) × 4 m (L) × 3 m (H) for each room. The wall thickness is 0,2 m. The French windows at the front face were centered of door configuration and have the width size of 2 m, and the height of window varies with the height of the wall between the window. $H + H_m = 4\ m$, where H is the height of the window, and H_m is the height of the wall between the windows. The fire canopy extended upper each window. According to the research of John H. Mammoser and Francine Battaglia on the geometrical shape of the balcony [11], the best effect to restrain the vertical spread of window outflow plume is the balcony without brick retraining walls and with open on both sides. For accurate calculation, the mesh size of the fire chamber and its superstructure is 0,1 m × 0,1 m × 0,1 m, and the other regional grid cell sizes are 0,2 m × 0,2 m × 0,2 m.

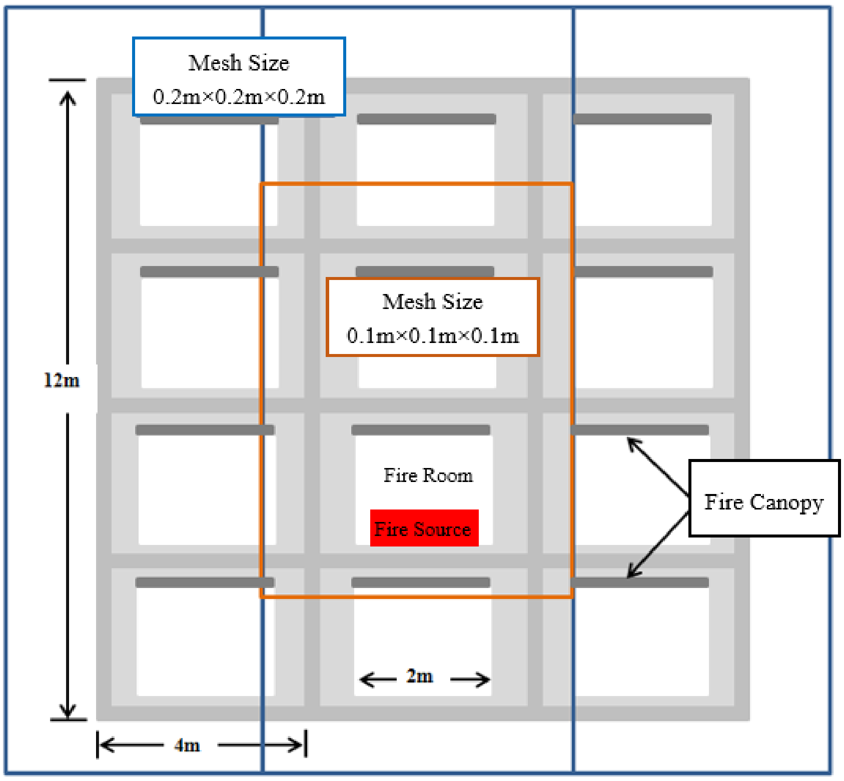


Figure 1. – Outline of model configuration

The fire load of the residential building is proportional to the decoration standard of the building. As the living standard of the residents increases, the fire load of the residential building is increasing. The type of fire growth is described by the unsteady t^2 model [15] commonly used in this model. The heat release of the fully development phase is stable and can be represent by the idealized parabolic equation $Q_c = \alpha t^2$. α : growth factor of fire heat release rate (kW/s^2), which can be divided into four types (slow growth, medium growth, rapid growth and ultra-fast growth). t: burning time after ignition. Q_c : the total heat release rate. In this paper, the growth factor is set 0,04689 ($\alpha = 0{,}04689$) [15], and the total heat release rate Q_c is set to 6 MW (normal), 10 MW (high fire load) and 20 MW (for the warehouse) according to the standard DGJ 08-88-2006 [16] combined with the actual engineering and research results in China.

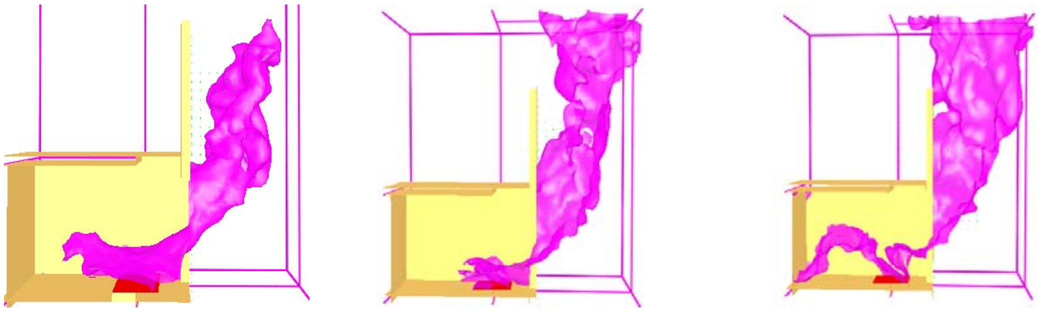
In this paper, we use $1500\,A\sqrt{H}$ to divide the single chamber combustion into fuel control or ventilation control fire [1, 5, 6, 17], where the A represents the area of the window, H is the height of the window. When the total heat release rate of the fire Q_c is less than $1500\,A\sqrt{H}$ kW, the chamber combustion is fuel-controlled fire. When the total heat release rate Q_c is exceeds $1500\,A\sqrt{H}$ kW, the replenished air is insufficient to support indoor combustion, and the fire develops to the ventilation control stage, and the overflow heat release rate of the outdoor flame can be expressed as:

$$Q_{ex} = Q_c - Q_{incide} = Q_c - 1500 A\sqrt{H}. \tag{1}$$

Fire risk criterion for building facade outflow plume. For non-combustible walls, when a fire occurs in the lower room and a lot of fire and smoke ejecting form the window, the upper building window glass is broken is the key to whether the building fire is further spread. In this paper, the temperature criterion of glass breakage will be used as the criterion for the risk of building facade outflow plume.

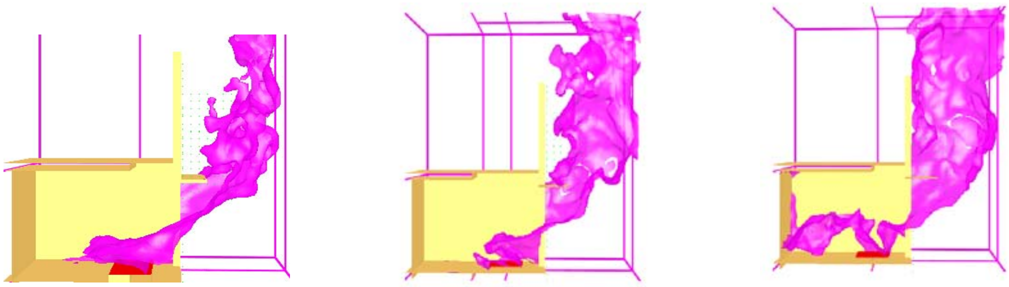
The experimental study [18] on the crushing behavior of 4 mm and 6mm float glass and 6mm and 10mm toughened glass under the single room real fire test based on ISO9705 full size experimental platform. It was found that the mean temperature of 4 mm thick float glass was 128,4 °C, and the mean temperature of 6mm thick float glass was about 142,4 °C for the first time breaking. The temperature of the first rupture of 6mm thick toughened glass was about 259 ~ 320 °C and 10 mm thick toughened glass was about 332 ~ 430 °C. Considering a certain safety factor, 120 °C is the critical point of rupture of the float glass, and 250 °C is the critical point of rupture of 6mm thick toughened glass, and 300 °C is the critical point of rupture of 10 mm thick toughened glass respectively.

Results and Discussion. In figure 2 is given the different kinds of isothermal surface of building facade at 250 °C. From the figure, it can be seen that with the increase of heat release rate, the danger area of building higher than 250 °C is increased. When the length of fire canopy is 0,5 m and total heat release rate is 6 MW, the window overflow plume can be effectively suppressed vertical spread. When total heat release rate increases to 10 MW, the window overflow plume partly across the fire canopy, but the temperature of the building facade above the fire canopy is lower than 250 °C. When total heat release rate increases to 20 MW, most of window overflow plume move across the fire canopy and the building facade above the fire canopy is all in the danger zone which can easily ignite the exterior wall and the upper room, that is, this fireproof construction cannot reduce the fire risk of building facade.



$Q_C = 6\,\mathrm{MW}$ $Q_C = 10\,\mathrm{MW}$ $Q_C = 20\,\mathrm{MW}$

(a) *Opening shape* $B = 0{,}1\,\mathrm{m}$, $H = 0{,}2\,\mathrm{m}$, $L_{hp} = 0\,\mathrm{m}$. L_{hp} *is the length of the fire canopy*



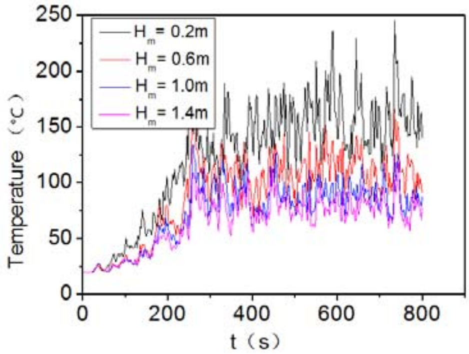
$Q_C = 6\,\mathrm{MW}$ $Q_C = 10\,\mathrm{MW}$ $Q_C = 20\,\mathrm{MW}$

(b) *Opening shape* $B = 0{,}1\,\mathrm{m}$, $H = 0{,}2\,\mathrm{m}$, $L_{hp} = 0{,}5\,\mathrm{m}$

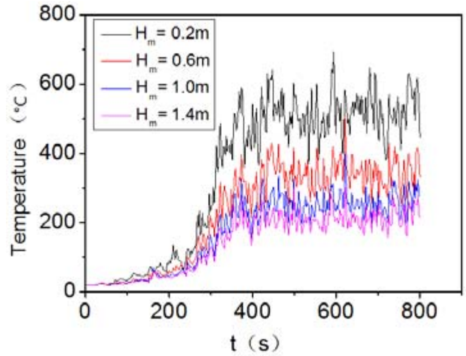
Figure 2. – Isothermal surface at 250 °C

Figure 3 shows the variation of the building facades temperature over time with different height of the wall between windows. It can be seen from the figure, the temperature distribution and the pulse amplitude increase with the increase of the total heat release rate in the room, and the effect of the wall between the windows on restraining the overflow plume vertical spread weaker and weaker. When the heat release rate is 6 MW and the height of the wall between the window greater than 0,6 m, the average temperature of the building facade is less than 100 °C, and the average heat flux is less than 5 kW/m^2. Under this fire protection construction, if the upper window is set up more than 6mm thickness of toughened glass and the height of the wall between windows is larger than 0,2 m, the toughened glass will not burn out and overflow plume will not ignite the upper room, and if the upper window is set up ordinary float glass and the he height of the wall between windows is larger than 0,6 m, the float glass will not burn out. When the heat release at 10 MW, the distance from the combustion chamber window is greater than 1m, the average temperature of the building facade is less than 250 °C. If the upper window is set up more than 6mm thickness of toughened glass, the toughened glass will not burn out. When the heat release at 20 MW, the average temperature of the building facade all more than 350 °C, which exceeded the fire endurance of the 6mm thick toughened glass.

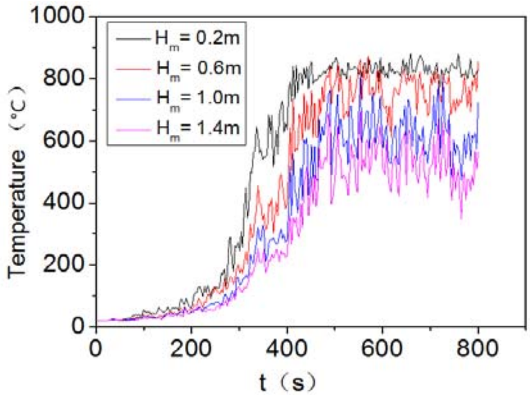
When the height of the wall between windows is fixed at 0,4 m, the fire hazard of the building facade is effectively reduced by the existing fire canopy from the figure 4. When the heat release rate is 6 MW and the length of the fire canopy increases form 0,2 m to 0,6 m, the average temperature of building facade at upper room window is below 100 °C. Under this condition, no matter what the material of the window glass will be taken, this fire protection construction can effectively inhibit the vertical spread of window overflow plume. When the heat release rate is 10MW and the length of the fire canopy is larger than 0,7 m, the average temperature of building facade is below 250 °C. In this case, the 6mm thick toughened glass can be used to protect the upper room. When the heat release rate is 20 MW and the length of the fire canopy is larger than 1 m, the average temperature of building facade at the upper room window is below 300 °C. In his case, the 10 mm thick toughened glass can be used to protect the upper room.



$Q_C = 6\,\text{MW}$

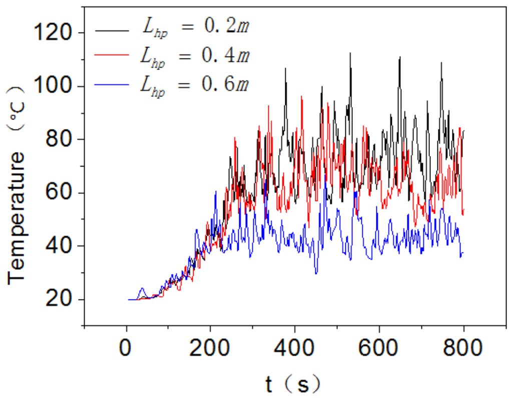


$Q_C = 10\,\text{MW}$

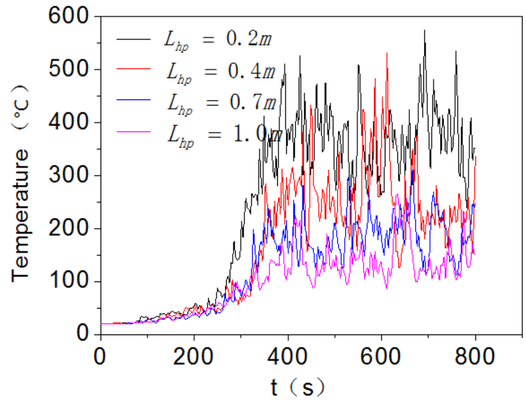


$Q_C = 20\;MW$

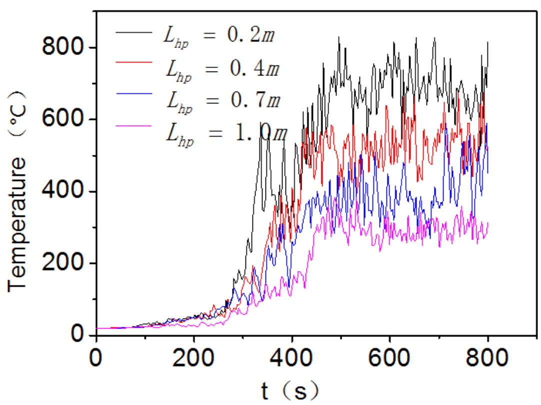
Figure 3. – Temperature curve alone the centerline above the upper room window ($L_{hp} = 0$ m)



$Q_C = 6\,\text{MW}$



$Q_C = 10\,\text{MW}$



$Q_C = 20\,\text{MW}$

Figure 4. – Temperature curve alone the centerline above the upper room window ($H_m = 0{,}4\,\text{m}$)

In order to provide technical guidance for building designers and fire safety assessment organization, it is necessary to proposed the combination plan of the fire canopy and the wall between windows to inhibit the vertical spread of window outflow plume. When the heat release rate of outside the chamber $Q_{ex} < 0$, the fire risk of the building facade is low because the indoor combustion is controlled by fuel and no obvious flame overflows from the window. Therefore, the single chamber combustion is considered only when the heat release rate of outside the chamber $Q_{ex} > 0$ to study the combination plan. At the same time, the fire resistance of building facade is different for various kinds of glass materials, which makes the method of predicting the temperature distribution of the building facade is different.

Lee Yee-Ping [1, 6] presents a dimensionless temperature distribution equation (2) based on the feature length l_1. This equation can represent the distribution of building facade temperature under free boundary conditions.

$$\Theta = \frac{\Delta T_Z / T_\infty}{\left(Q_{ex}^*\right)^{2/3}} \left(\frac{T_Z}{T_\infty}\right)^{-2/3} = function\left(\frac{Z - Z_n}{l_1}\right) \tag{2}$$

$$Q_{ex}^* = \frac{Q_{ex}}{C_p \rho_\infty T_\infty \sqrt{g} l_1^{5/2}} \tag{3}$$

Where: Z is the vertical height, Z_n is the height of the neutral surface, the position of the neutral surface is approximately 0,4 H [2]. $\Delta T_z = T_z - T_\infty$, T_Z is the temperature value for the height Z. T_∞ is the ambient temperature. Q_{ex}^* is the dimensionless overflow heat release rate. C_p is the constant pressure specific heat capacity, ρ_∞ is the environmental density.

Jiajia Fu et al [19]. proposed the equation of temperature distribution outside the building facade under the restriction of fire canopy. The applicable condition of this equation is that the length of the fire canopy is greater than 0,1 m and the dimensionless overflow heat release rate is greater than 1,3.

$$\frac{T_{L=0} - T}{T_{L=0} - T_\infty} = 0.85\left(\frac{L_{hp}}{Z - Z_n}\right)^{0,20} \tag{4}$$

Where $T_{L=0}$ is the value of the temperature of building facade without the fire canopy restriction. L_{hp} is the length of the fire canopy.

Therefore, using the formula (1) and (3), we can get the dimensionally heat release rates the dimensionless overflow heat release rate Q_{ex}^* is −0,39, 0,27 and 1,93, respectively, when the total heat release rate Q_c is 6 MW, 10 MW and 20 MW. That is, when the total heat release rate is 6 MW, the chamber combustion is fuel-controlled fire. When the total heat release rate is 10 MW, the dimensionless overflow heat release rate is less than 1,3 ($Q_{ex}^* < 1{,}3$), and the formula (4) can't be used to calculate the temperature. When the total heat release rate is 20 MW, the dimensionless overflow heat release rate is larger than 1,3 ($Q_{ex}^* = 1{,}93 > 1{,}3$), and the formula (4) can be used to calculate the temperature distribution of building facade.

In figure 5, The red line represents the temperature threshold 250 °C of 6 mm toughened glass broken. Above the red line is a dangerous combination of fire protection scheme, and below the red line is a relatively safe combination of fire prevention scheme.

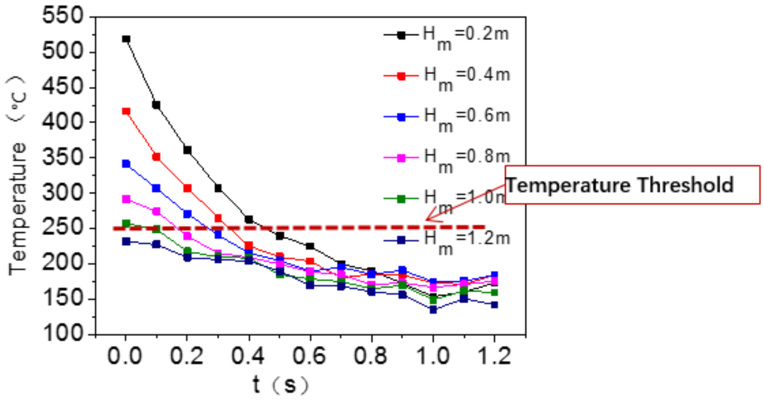


Figure 5. – Temperature distribution of building facade for different fire canopy width and wall height between windows at $0 < Q^*_{ex} < 1{,}3$

For the combination of 0,2 m wall height between windows and 0,5 m fire canopy width and the combination of 0,4 m window wall height and 0,4 m fire canopy width, the average temperature of upper room window is lower than 250 °C. Therefore, it can obtain the different combination schemes for wall height between windows and fire canopy width, as shown in table 1.

Table 1 The combination of the fire canopy width and the wall height between windows ($0 < Q^*_{ex} < 1{,}3$)

Fire Canopy Width (m)	Wall Height between Windows (m)
0.0	1.2
0.2	0.8
0.4	0.4
0.6	0.2

Conclusion. When the height of the wall between the upper and lower window or the length of the fire canopy does not meet the requirements of the code for fire protection design, we can set both at the same time, or improve the window glass fire rating to achieve the building facade fire design requirements.

When the window glass is made of 6mm thick toughened glass and the dimensionless overflow heat release rate $0 < Q^*_{ex} < 1{,}3$, the combination scheme (see in Table 1) of the fire canopy and the wall between the windows can be used to meet the building fire requirements.

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