

2010

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Chow, C. L. and Chow, W. K., "Fire Safety Concern on Well-Sealed Green Buildings with Low OTTVs" (2010). *International High Performance Buildings Conference*. Paper 1.
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Fire Safety Concern on Well-sealed Green Buildings with Low OTTVs

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ABSTRACT

The Overall Thermal Transfer Value (OTTV) of building façade is controlled in many big cities in East Asia such as Hong Kong and Singapore for building energy conservation. For example, the OTTV is limited to 20 Wm⁻² in Hong Kong to reduce solar heat gain. Buildings are also sealed up to reduce cooling load of the mechanical heating and cooling systems. Therefore, heat generated in an accidental fire in well-sealed buildings with low OTTVs would be trapped indoor. The time to flashover would then be shortened. In this paper, fire safety of concealed green buildings with low OTTVs will be discussed. A heat balance equation in a compartment fire was set up. Common buildings materials including brick, concrete, gypsum plaster, glass panels, fibre glass composites and timber were then evaluated. Façade materials are proposed to be tested under flashover conditions.

1. INTRODUCTION

Sustainable buildings are the design target all over the world (Chow and Chow, 2003). Constructing energy efficient buildings is a key point in reducing the amount of carbon emission. In places including Singapore, Malaysia and Hong Kong, the heat transferred through the building envelope is controlled by using Overall Thermal Transfer Value (OTTV) (Buildings Department, 1995; Chow and Chow, 2004). OTTV has to be kept at a very low value to reduce solar heat gain through the building envelop. For example, the OTTV is up to 20 kWm⁻² in the suggested guide in Hong Kong. This can be achieved either by reducing the window-to-wall area ratio or by using materials with higher thermal insulation. However, there are potential fire risks in thermally insulated buildings with low OTTV. Providing better thermal insulation of the envelopes with appropriate building materials would reduce the heat lost from the compartment when there is a fire. The heat emitted from a fire is trapped in the compartment, giving higher chance to flashover (Thomas and Bullen, 1979). There were many fires on air-conditioned buses in the Far East cities including Hong Kong and Shanghai (e.g. Chow, 2000; Chow, 2001) reported in the past few years. The bus envelopes were made of good thermal insulation materials such as sandwich panels. Only the engine chassis was left in less than 15 minutes after the ignition. But comparing with the poor thermally insulated metal sheet bus in 1980s, flashover was difficult to onset. The same concern was raised in buildings with better thermal insulation. The associated fire safety aspects for well-lagged buildings with low OTTV thermal insulating materials should be investigated and will be discussed in this paper.

Three parts should be considered in fire hazard assessment for façades with better thermal insulation:

- Estimating the ratio of heat lost through the wall to the heat release rate of a fire.
- Plotting heat lost rate through wall and heat release rate of a fire against gas temperature rise in the compartment (similar to Semenov's diagram in classical explosion studies) for studying the possibility of transition to flashover.
- Studying the fire growth time for walls of different thermal inertia with empirical relations.

2. MATERIALS WITH BETTER THERMAL INSULATION

A heat balance equation (e.g. Chow, 2000; Chow, 2001) in a compartment inside a building can be set up by considering the heat gain due to the fire \dot{Q}_f (in W); heat lost through the wall \dot{Q}_L (in W); and the heat carried out of the enclosure by smoke determined by the outflowing rate \dot{m}_g (in kg s^{-1}) in terms of the temperature rise ΔT (in $^{\circ}\text{C}$) in the compartment and the specific heat capacity C_p of air (say of value $1100 \text{ J kg}^{-1}\text{K}^{-1}$):

$$\dot{m}_g C_p \Delta T = \dot{Q}_f - \dot{Q}_L \quad (1)$$

\dot{Q}_L includes the heat transfer through the wall surfaces and then lost to outside. This term is roughly proportional to ΔT and can be expressed in terms of the heat transfer coefficient h_w (in $\text{W m}^{-2}\text{K}^{-1}$) at exposure time t which depends on the thermal conductivity k_w (in $\text{W m}^{-1}\text{K}^{-1}$), density ρ_w (in kg m^{-3}), specific heat capacity C_w (in $\text{J kg}^{-1}\text{K}^{-1}$), surface area A_w (in m^2) and thickness d_w (in m) of the compartment walls:

$$\dot{Q}_L = h_w \cdot A_w \cdot \Delta T \quad (2)$$

and h_w is:

$$h_w = C_1 \text{Max} \left\{ \left(\frac{k_w \rho_w C_w}{t} \right)^{0.5}, \frac{k_w}{d_w} \right\} \quad (3)$$

Note that $k_w \rho_w C_w$ is also known as the thermal inertia of the materials I_w (in $(\text{W m}^{-2}\text{K}^{-1})^2\text{s}^{-1}$). The time to ignition of materials depends on I_w . Value of C_1 becomes a constant and was measured by Deal and Beyler (1990) to be 0.4 for compartment fires when the exposure time becomes longer than the thermal penetration time t_p (in s):

$$t_p = \left(\frac{\rho_w C_w}{k_w} \right) \left(\frac{d_w}{2} \right)^2 \quad (4)$$

The outflowing rate of smoke \dot{m}_g is the sum of the inflow rate of air and the burning rate of the fuel. For a near flashover or post-flashover fire in a room with small openings and burning rate appeared to be stoichiometric, the mass flow rate of air entrainment was analyzed by Kawagoe (1958) to be proportional to the ventilation factor $A_o \sqrt{H_o}$ of the opening, with A_o (in m^2) and H_o (in m) being the area and height respectively of the opening. This was further discussed by Chow (2009) on studying thermal induced air flow through doorways with Computational Fluid Dynamics.

For a ventilation-controlled fire, the burning rate of the fuel, though much smaller than the mass flow rate of air entrainment, depends also on the ventilation factor. All these suggested that \dot{m}_g (in kg s^{-1}) is related to the ventilation factor (e.g. Chow, 2009; Babrauskas, 1980) as:

$$\dot{m}_g = 0.5 A_o \sqrt{H_o} \quad (5)$$

The heat lost through the envelope \dot{Q}_L is given by equation (2), and the ratio γ of heat lost through the compartment wall to the heat flowing out with hot gas is:

$$\gamma = \frac{h_w A_w}{0.5 C_p A_o \sqrt{H_o}} \quad (6)$$

The percentage β of heat lost through wall with respect to the rate of heat generated by the fire is then given by the following expression from equation (1):

$$\beta = \frac{\dot{Q}_L}{\dot{Q}_f} = \frac{\gamma}{1 + \gamma} \quad (7)$$

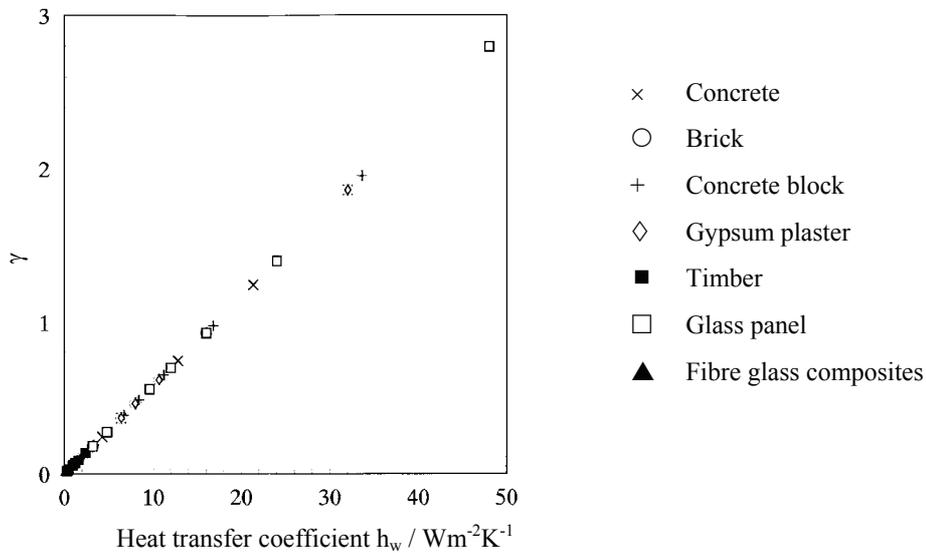
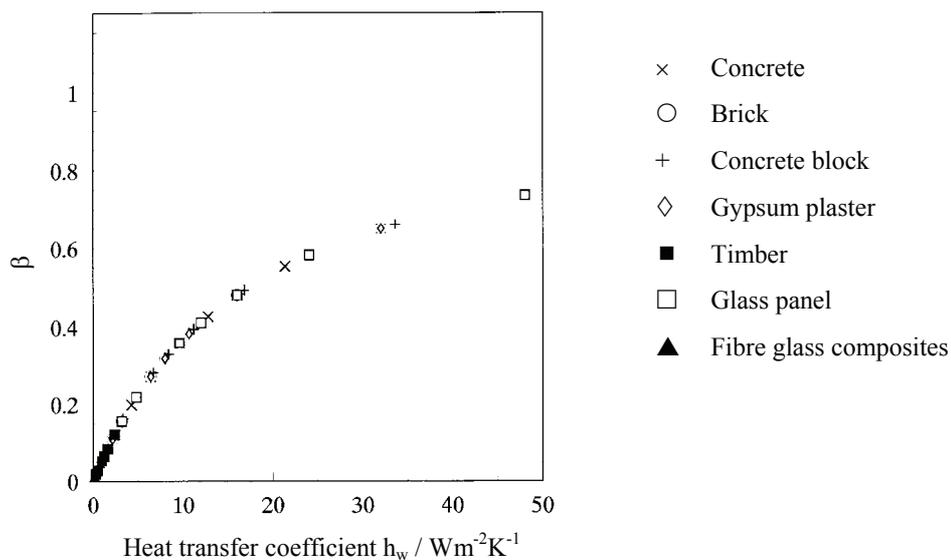
3. ONSETTING FLASHOVER

To study the effect of wall materials on the possibility of having flashover, heat lost through walls is being assessed. A typical building of 10 m long, 6 m wide and 3 m high with an open window of width 3 m and height 1 m is considered and, giving A_w of 96 m² and $A_o \sqrt{H_o}$ of 3 m^{5/2}. Key thermal data on materials including brick, concrete, gypsum plaster, glass panels, fibre glass composites, and timber tested in a project funded on studying double-deck bust fires (Chow, 2000; Chow, 2001) are useful in studying onsetting flashover in a building fire. Values of t_p , γ and β were calculated for wall thickness d_w varying from 1 cm to 15 cm. Results were reported (Chow, 2000; Chow, 2001; Chow and Chow, 2004) together with physical properties ρ_w , C_w and k_w .

Variation of γ and β against h_w are plotted in Figures 1 and 2. In view of equation (7), γ is proportional to h_w . Materials with higher h_w would give higher ratio of heat lost through wall, reducing the heat left to raise the air temperature.

As reported before (Chow, 2000; Chow, 2001), β for poor thermal insulation such as steel sheet would have high value of 1. The heat lost rate through wall is much bigger and so it takes a longer time to heat up the compartment air. Materials with good thermal insulation such as fibre glass composites and timber would have very low heat lost through wall, having β less than 0.2. Therefore, there will be a higher chance to have flashover as the indoor air will be heated up.

The wall thickness d_w would play a significant role in thermal insulation. In view of equation (3) on h_w and values on computed β and γ , h_w reduced as d_w increased. It takes a much longer time for heat to conduct through the wall and then be lost by convection and radiation in the exterior side. Taking concrete as an example, values of t_p increased from 0.5 min to 105.5 min by increasing d_w from 1 cm to 15 cm, h_w decreased from 64 Wm⁻²K⁻¹ to 4.3 Wm⁻²K⁻¹, reducing β from 0.79 to 0.20. Thicker materials would have lower heat loss rates, so easier to get flashover. However, the effect of thickness would not be significant when the material is thicker than a certain value as pointed out by Thomas (1979).

Figure 1: Variation of γ for common façade materialsFigure 2: Variation of β for common fuel envelope materials

Thermal insulation fibre glass materials for energy conservation of thickness 15 cm to 1 cm would have small β from 0.01 to 0.08. The heat generated from a fire in a room made of those materials would be trapped, giving shorter time to flashover. Further, the organic bonding materials are easily ignited if fire retardants are not provided. But under high radiation heat fluxes in a big fire, those materials will also be ignited even if they are treated with fire retardants.

Quasi-steady states can be found when \dot{Q}_f is the same as \dot{Q}_L . Plotting these two terms against ΔT would give curves similar to Semenov's diagram in classical thermal explosion theory for determining the criteria for flashover.

Rate of heat lost curves for \dot{Q}_L expressed in terms of h_w , A_w and ΔT are plotted against the temperature rise ΔT in Figure 3 for concrete and glass panels. The two-layer zone model HotLayer in FIREWIND 3.3 (1998) was applied to calculate steady value of ΔT which corresponds to constant \dot{Q}_f . In this way, a curve \dot{Q}_f can be plotted against ΔT . Note that the minimum heat release rate for flashover is 2.8 MW in this building with the specified ventilation condition.

For thermal insulating materials like concrete or glass panels, wall thickness is important in affecting heat flow through the wall. Glass panel of 4 cm thick would have greater heat lost than the heat generated in a fire as shown in Figure 3. Concrete wall of 4 cm thick might give \dot{Q}_L less than \dot{Q}_f for ΔT up to 1850°C, but for those glass panels of 2 cm thick, \dot{Q}_L is less than \dot{Q}_f for ΔT from 150°C to 1250°C. If ΔT is slightly below 150°C due to an accidental fire, it is likely to have transition to flashover under some thermal perturbation.

4. THERMAL INERTIA

It was further proposed by Thomas (e.g. Thomas, 1979; Thomas and Bullen, 1979) that the growth time t_g (in s) of a compartment fire for an exponential rise in burning rate depends on I_w as:

$$t_g = A_f + B_f I_w^n \quad (8)$$

In the above equation, n is an exponent of value less than 0.5; A_f and B_f depend on the fire details.

Values of the first term A_f in equation (8) might be much greater than the second term $B_f I_w^n$ (Thomas, 1979) for a fast growing fire. Value of A_f under a slow growing fire might be about 20 $B_f I_w^n$, effect of wall materials on the fire growth is not significant. But when A_f and $B_f I_w^n$ are of similar magnitude, the result will be very different.

Assuming A_f is roughly similar to B_f , t_g (expressed in arbitrary unit) is plotted against I_w in Figure 4. The wall materials are also labeled to illustrate the relative values of t_g . Note that much longer time to flashover under an accidental fire would be resulted for materials with high values of I_w .

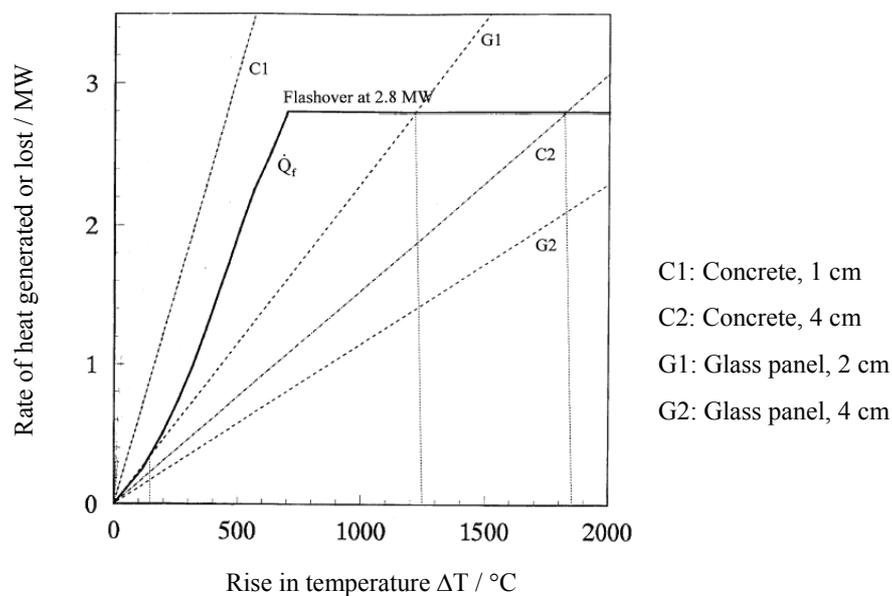


Figure 3: Heat lost rate for common façade materials

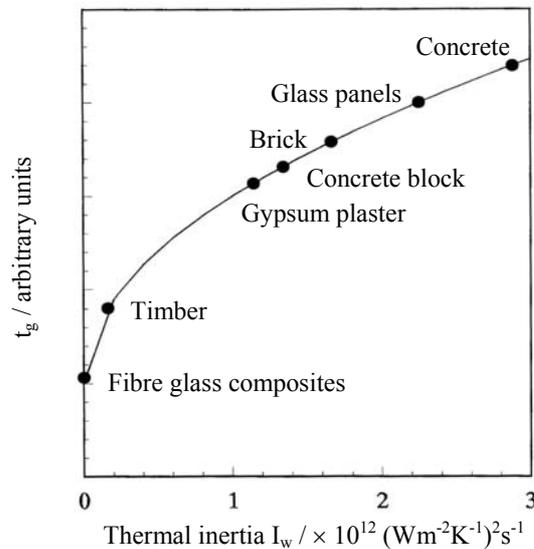


Figure 4: Fire growth time thermal inertia

5. CONCLUSION

As discussed in the literature, environmental control system in new architectural features for green or sustainable buildings should be operated with less energy (e.g. Cole, 1999) in order to give a healthy environment. The use of good thermal insulation materials for building envelopes might give a higher chance of transition to flashover as pointed out in above.

Using poor thermally insulated materials would give higher heat lost, hence increasing the cooling or heating load of the heating, ventilation and air-conditioning system. New architectural features such as double-skin façade (Chow and Hung, 2006) might give a lower heat lost rate. However, as discussed in above, it is much easier to onset flashover for buildings with good thermally insulated façade. Heat generated in a fire would be trapped to give rapid rise of room air temperature. It appears that poor thermally insulated materials like glass with higher heat lost might be safer in a fire. The chance of having flashover is then reduced. Unfortunately, glass panels itself will be cracked at a certain temperature (Skelly *et al.*, 1991), normally around 200°C. Large glass sheets in a big room fire would even fall down. More air will be entrained to burn the high amount of combustibles stored to give a very big fire. Therefore, studying the response of glass façade under a big fire is essential. The related study is in progress and will be reported later.

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