FIRE RESISTANCE RQUIREMENT IN MEDIUM SIZE ROOM
Determining condition on which ventilation scenarios hardly alter the value

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ABSTRACT

The potential hazard of fire to structural building may be characterized in term of fire resistance requirement. Its value has been suggested dependent on geometry of the room, fire load contained, ventilation/opening and thermal properties of the compartment boundaries. Previous numerical study shows that the effect of ventilation scenarios, whether increasing or decreasing to the value of fire resistance requirement, depends on thermal absorptivity of surface material comprising the room. It implies that there is a condition of thermal absorptivity on which ventilation scenarios may not alter the fire resistance requirement. This current study is an effort to determine such condition. The results indicate that for the room size and ventilation scenarios given in this study, the difference in fire resistance requirements could be set within only 0.02 hours. The key to attain this condition is by setting the thermal absorptivity of the wall at 7500 $Jm^{-2}s^{-1/2}K^{-1}$.

Keywords: compartment boundary, fire resistance requirement, thermal absorptivity, ventilation scenario

1. INTRODUCTION

Safety of building against fire should be a prime priority to avoid loss of both life and properties. Proper design of building to reach certain fire safety involved a variety of aspects: architectural, structural, mechanical and electrical services, etc. In term of structural performance of building against fire, there are three modes of failure i.e. structural load bearing, integrity and insulation failures that should be bear in mind by building designer. The three failure modes represent unsuccessful of particular element/building in preventing the spread of fire by means of structural destruction, penetration of flame to adjacent room/building and heat flux penetrating the barrier through its thermal conductivity which could ignite adjacent room/building, respectively.

To achieve a good structural performance of building in the event of fire, a concept of fire resistance has been introduced. Fire resistance requirement, expressed in time, is a term used to describe the resistance needed for building to survive a burn-out of its contents without collapse, loss of integrity, and failure of its insulation capability. When the fire resistance requirement of particular element/building has been determined, it is deemed that by choosing material with fire resistance (proved by test or calculation) more than fire resistance requirement will keep the element/building survive and prevent the spread of fire.

The value of fire resistance requirement depends on various factors: combustible materials contains in the building, ventilation, etc. Law (1971) and Lie (1978) took account of fire load and of the geometry of the enclosure in estimating the resistance necessary in terms of the standard fire, and allowed for fires more or less severe than the standard. Harmathy (1980) showed that fire resistance requirement could be characterized in terms of a parameter that he called the 'normalized heat load'. The gain from this innovation was that it became possible to take into account the thermal properties of the construction. Where some part of the compartment boundaries was able to absorb heat because of high thermal conductivity and capacity, the compartment as a whole suffered a correspondingly less severe fire.

Mehaffey and Harmathy (1981) developed an approximate formula to compute the normalized heat load under real-world fire conditions. Application of normalized heat load to estimate the fire resistance requirement of particular enclosures was further described in detail by Harmathy (1993). The input of parameters required for the computation of normalized heat load and hence, fire resistance requirements of room are also given in the reference (Harmathy, 1993). These include: height of ventilation, area of ventilation, ventilation parameter, surface area of compartment boundary, thermal absorptivity, fraction of heat evolved from flaming combustion inside the fire compartment, fire load, etc.

Kristiawan (2009) indicates that fire resistance requirement of medium size room calculated based on the concept of normalized heat load is affected by ventilation in the following way. Fire resistance requirement is increased or decreased due to ventilation depends on thermal absorptivity of surface material comprising the room. It implies that there may be a condition of thermal absorptivity on which ventilation scenarios hardly alter the fire resistance requirement. Such condition is obtained by changing thermal absorptivity of wall to a fix value of 7500 $Jm^{-2}s^{-1/2}K^{-1}$.

2. FIRE LOAD, GEOMETRY, VENTILATION SCENARIOS AND COMPARTEMENT BOUNDARIES OF THE INVESTIGATED ROOM

The room geometry (area of 3800 x 4200 mm^2 and height of 2400 mm) and ventilation scenarios used for the current study are similar to those used by Saber et al (2008) as can be seen in Figure 1. However, the fire load contained in the room is different to that of Saber et al. For the current study, the room represents typical room in dwelling and so the fire load is about 30.1 kg/m^2 (Petterson et al., 1976) Meanwhile, four scenarios of surface materials of compartment boundaries are proposed (see Table 1). Thermal properties of compartment boundaries are calculated based on the individual property of material (Table 2) comprising the compartment.

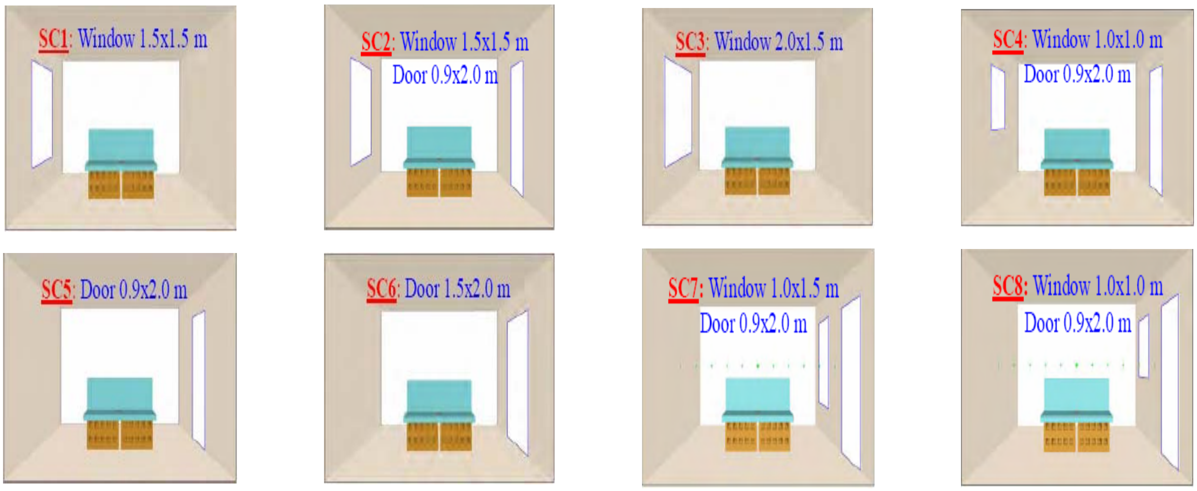


Figure 1. Ventilation Scenarios of the room

Table 1. Compartment boundary scenarios

Compartment Boundaries	**Surface Material**		
	Ceiling	**Wall**	**Floor**
CB1	Plasterboard	Plasterboard	Wood
CB2	Gypsum	Plasterboard	Wood
CB3	Gypsum	Plasterboard	Marble
CB4	Gypsum	Brick	Marble

Table 2. Thermal properties of surface materials (adapted from Harmathy (1993; Karlsson and Quintiere (2000)

Materials	**k ($Wm^{-1}K^{-1}$)**	**ρ, (kgm^{-3})**	**c ($Jkg^{-1}K^{-1}$)**
Steel	44.0	7800	460
Marble	2.0	2650	1000
Concrete	1.7	2250	1200
Brick	1.0	2100	900
Lightweight Concrete	0.50	1450	1000
Plaster board	0.25	750	2500
Gypsum	0.48	1440	850
Wood	0.15	550	1800
Mineral Wool	0.04	160	1150

k = thermal conductivity; ρ = density; c = specific heat

3. METHOD OF CALCULATIONS

Based on the normalized heat load concept, Mehaffey and Harmathy (1981) derived the following expressions for the assessment of the fire resistance requirement (τ_d):

$$\tau_d = 0.11 + 16.0x10^{-6} H'' + 0.13x10^{-9} (H'')^2 \quad \text{.......(1)}$$

where 0.11, 16x10^{-6}, and 0.13x10^{-9} are dimensional constants, and design value of normalized heat load ,*H"*, could be related to the normalized heat load under real-world fire condition, *H'*, as follows:

$$H'' = H' \exp(\beta\sqrt{\Omega_1^2 + \Omega_2^2 + \Omega_e^2} \quad \text{....... (2)}$$

with β is a factor to allow for certain probability failure, Ω_1 and Ω_2 represent coefficient variations of *H'* and *H"* , respectively and Ω_e denotes coefficient variation for the error associated with the use of the following two equations:

$$H' = 1.06x10^6 \frac{(11.0\delta + 1.6)A_F L_m}{A_t\sqrt{k\rho c} + 935\sqrt{\Phi A_F L_m}} \quad \text{....... (3)}$$

$$\delta = 0.79\sqrt{h_C{}^3 / \Phi} \text{ or 1 whichever is less} \quad \text{....... (4)}$$

with δ = fraction of heat evolved from flaming combustion inside the fire compartment, dimensionless, A_F = floor area of compartment, m^2, L_m = mean specific fire load, kg m^{-2}, A_t = total surface area of compartment boundaries, m^2, $\sqrt{k\rho c}$ = thermal absorptivity of compartment boundaries, J m^{-2} s$^{-1/2}$ K^{-1}, and Φ = ventilation parameter, kg s^{-1} and h_c = height of the compartment, m. Ventilation parameter is calculated using the following equation:

$$\Phi = \rho_a A_v \sqrt{g h_v} \quad \text{....... (5)}$$

In Eq.2. a value of Ω_e = 0.101 is suggested by Mehaffey and Harmathy (1984), while Ω_1 and Ω_2 are determined as follows:

$$\Omega_1 = \frac{\sigma_L}{L_m} \frac{A_t\sqrt{k\rho c} + 468\sqrt{\Phi A_F L_m}}{A_t\sqrt{k\rho c} + 935\sqrt{\Phi A_F L_m}} \quad \text{....... (6)}$$

$$\Omega_2 = 0.9\Omega_\tau \quad \text{....... (7)}$$

with Ω_τ is somewhere between 0.01 and 0.15 and a value of 0.1 may be used for all purpose. If the boundaries of the compartment are formed by different materials, the thermal absorptivity should be looked upon as a surface-averaged value, to be calculated as:

$$\sqrt{k\rho c} = \frac{1}{A_t}(A_1\sqrt{k_1\rho_1 c_1} + A_2\sqrt{k_2\rho_2 c_2} + A_3\sqrt{k_3\rho_3 c_3} + ...) \quad \text{.......(8)}$$

where the numerical subscripts refer to the various materials and surfaces formed by them. Ventilation parameter should be modified if there are multiple vertical openings by using the weighted average of height of the ventilation openings h_{cave}, calculated as follows:

$$h_{cave} = \frac{\sum A_{vi} h_{ci}}{\sum A_{vi}} \quad \text{....... (9)}$$

where A_{vi} and h_{ci} are the area and height of the ith opening, and the summations are taken over all the vertical openings.

4. RESULTS AND DISCUSSION

Thermal absorptivity of all materials used in this study has been determined and their values are then employed to calculate thermal absorptivity of the room boundaries using Eq.8. The results of calculated thermal absorptivity of compartment boundaries with a variety of ventilation scenarios are presented in Figure 2. As can be seen in Figure 2, the dominant factor affecting thermal absorptivity is type of surface material used to line the room. As for CB3 and CB4 consist of marble with relatively high thermal absorptivity (2300 J m^{-2} s$^{-1/2}$ K^{-1}) in comparison to others (minimum value =390 J m^{-2} s$^{-1/2}$ K^{-1}for wood and maximum value= 935 J m^{-2} s$^{-1/2}$ K^{-1} for brick), it leads to give significant effect on the value of thermal absorptivity of the room. The effect of ventilation scenarios on thermal absorptivity is hardly recognised as shown in Figure 2. Theoretically, the effect of ventilation scenarios on thermal absorptivity could be related to the modification of surface area of compartment (in this case wall) as indicated in Eq.8. However, it should be noted that surface area itself only acts for calculating the average value of thermal absorptivity if the room consist of difference surface materials.

The fire resistance requirement of the room investigated in this research is presented in Figure 3. As expected, the fire resistance requirement is influenced by both compartment boundaries and ventilations. When the room is comprised with surface materials leading to high thermal absorptivity, the fire resistance requirement will be reduced and vice versa. For the given ventilation scenarios, the lowest and highest value of fire resistance requirements are found on SC2 and SC5, respectively.

Now the same rooms with the same variety of compartment boundaries and ventilation scenarios are evaluated further by modifying the thermal absorptivity of the wall with a value of 7500 J m^{-2} $s^{-1/2}$ K^{-1}. The result are given in Figures 4 and 5. It is clearly shown that increasing thermal absorptivity of the compartment boundaries up to a value of more than 4200 J m^{-2} $s^{-1/2}$ K^{-1} by modification of thermal absorptivity of wall could result in a reduction of fire resistance requirements of the rooms. And the values of fire resistance requirements seems to be in equivalent for all ventilation scenarios.

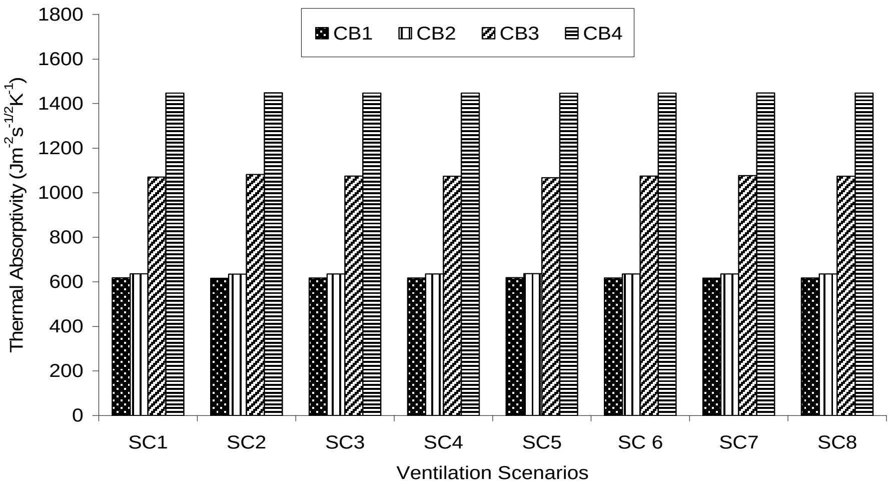


Figure 2. Thermal absorptivity of the investigated rooms

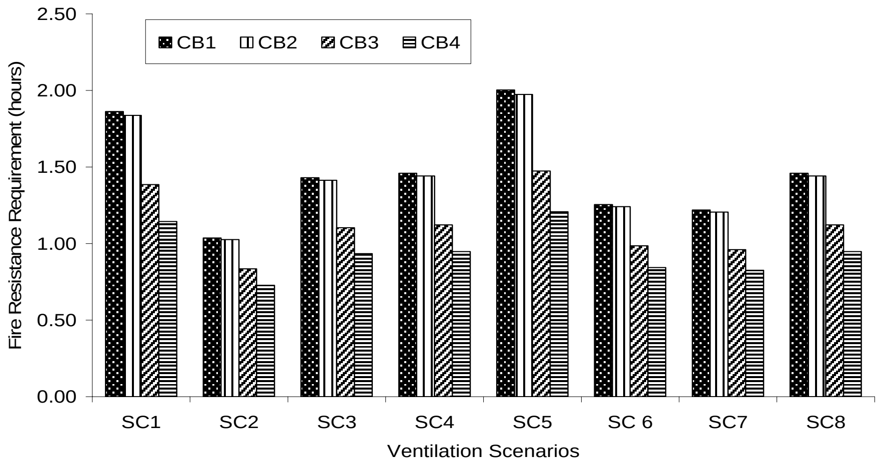


Figure 3. Fire resistance requirement of the investigated rooms

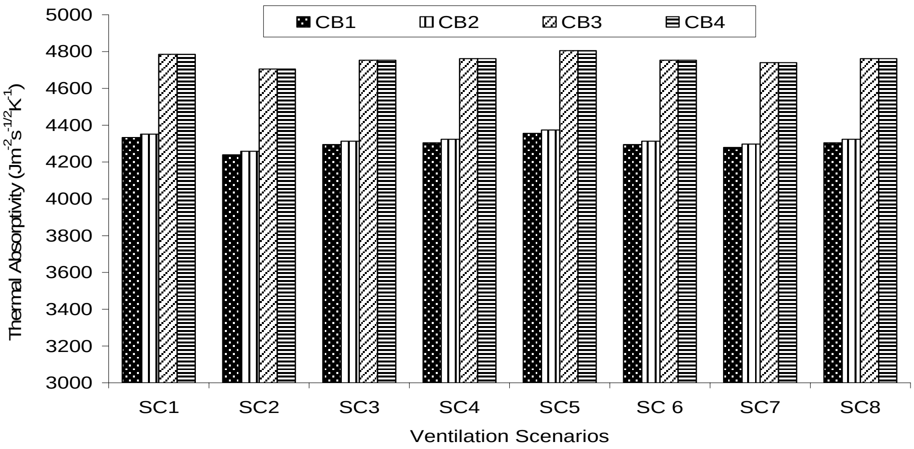
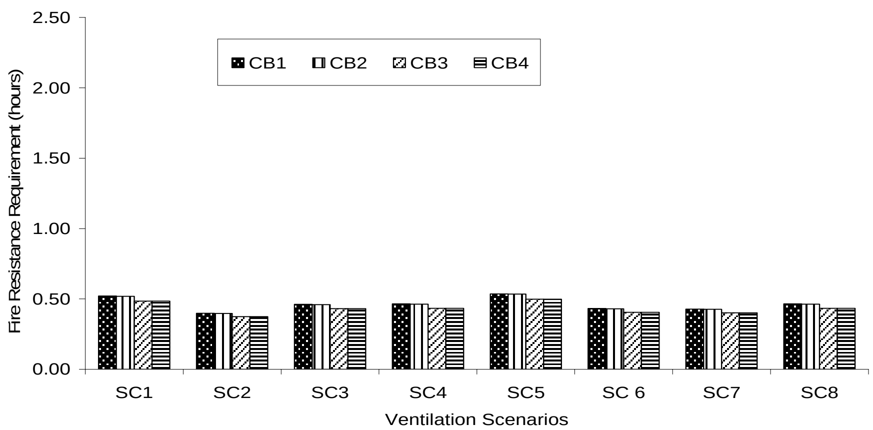


Figure 4. Thermal absorptivity of the investigated rooms when the wall is made of material with a value of thermal absorptivity at 7500 J m^{-2} $s^{-1/2}$ K^{-1} i



4. Fire resistance requirement of the investigated rooms when the wall is made of material with a value of thermal absorptivity at 7500 J m^{-2} $s^{-1/2}$ K^{-1}

5. CONCLUSION

This study has shown that effect of ventilation scenarios on the fire resistance requirement of the investigated room is almost neglected when thermal absorptivity of the room is above 4200 J m^{-2} $s^{-1/2}$ K^{-1}. This is achieved if thermal absorptivity of the wall is chosen to be 7500 J m^{-2} $s^{-1/2}$ K^{-1}.

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