Applied Mechanics and Materials Vols. 465-466 (2014) pp 480-484
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doi:10.4028/www.scientific.net/AMM.465-466.480

Numerical investigation on the effect of down stand structure in fire compartment on smoke contamination atrium upper balconies.

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Keywords: Atrium, Smoke Contamination, Down stand structure, Balcony, Fire compartment.

Abstract:

Atrium is gaining popularity in the modern societies because of its special attraction. However, during fire incident it causes significant risk due to its open spaces between floors. In atriums smoke can move easily to upper floors through these open spaces and causes smoke contamination of the atrium upper floors. Moreover, presence of down stand structure at the fire compartment opening is required in any shop in atrium shopping mall to display the trade name of the shop. This study investigated the effect of down stand structure on smoke contamination of upper balconies of an atrium by using Fire Dynamic Simulator, CFD software. A correlation that predict the smoke contamination occurrence in the presence of fire compartment down stand structure is developed. The results shows that down stand structure resulted in increasing the effect of smoke contamination in upper floors of an atrium.

Introduction:

Fire is the human enemy that is destructive in nature and cause sorrow and anxiety in homes when it consumes lives [1]. Fire in atriums may cause loss of life and property. Previous studies showed that more than 50 % of deaths occurred in fire accidents because of inhalation of smoke [2]. Fire releases smoke which has toxic effects because combustion product contains some irritant chemicals and asphyxiant gases like CO, CO_2 and hydrogen cyanide (HCN).

Atrium in a shopping mall contains several levels which has shops, offices and corridors. However, atrium can present significant risks to building occupants because of the open spaces in it, which allow smoke to spread from the origin of fire to upper floors. Experimental and modeling studies related to smoke contamination in atrium have been performed by researchers [3-5]. They found that when smoke plume flows out of the fire compartment opening and moves upwards in the atrium it will curl into the atrium upper spaces (balconies) resulting in smoke contamination. Tan [4] observed this contamination in his experimental investigation on smoke contamination in a scaled atrium model and he concluded that smoke contamination in upper balconies occurred when temperature difference between ambient and balcony temperature reaches 10°C. Ho [5] utilized computational fluid dynamics (CFD) technique to verify Tan's results and then upgraded the model to full scale. However, [4-5] did not model a down stand structure at the fire compartment opening which is required in any shop in shopping mall to display the trade name of the shop. Harrison [6] has modeled the down stand structure to study its effect on rising plume behavior but he did not studied the effect of down stand on smoke spread in atrium upper floors. He reported that the presence of down stand at the fire compartment opening could cause the plume leaving the fire compartment to rise vertically closer to atrium upper floors openings. Such behaviour may have significant implications on smoke contamination. As mentioned, although

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every shop in atrium has down stand structure to display its trade name but past research [3-5] has not modeled the effect of down stand structure at fire compartment opening on smoke contamination in atriums.

Therefore, the objective of this paper is to investigate the effect of down stand structure at fire compartment opening on smoke contamination in upper balconies of atrium.

Model Development:

Full scale five balconies atrium with down stand at fire compartment exit has been modeled in this study. The depth of down stand is 1m and it is located at the exit of fire compartment opening as shown in Fig. 1.

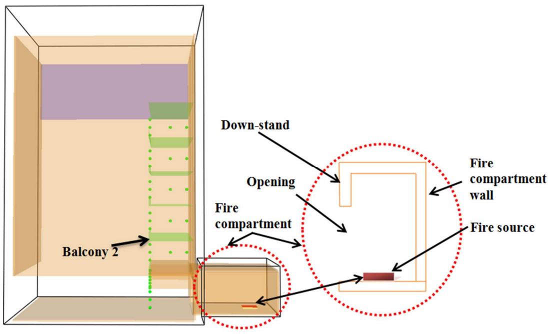


Fig. 1: Five balconies atrium with down stand structure.

The balcony breath, *b* and opening width of fire compartment, *w* was varied in every case. Fire Dynamic Simulator (FDS) version 5, CFD software is used to simulate the fire and smoke. Mesh size (element size) of 200 mm for full scale model is used by using following equations [7];

$$n^*_{spill} = \frac{D^*_{spill}}{\Delta X} \geq 0.9 \tag{1}$$

$$D^*_{spill} = \left(\frac{Q_c / w}{\rho C_p T \sqrt{g}} \right)^{2/3} \tag{2}$$

Where D^*_{spill} is characteristic length of plume for determining the grid size (m), n^*_{spill} is coefficient for determining the grid size, ΔX is grid dimension in x-axis, Q_c is convective heat flow layer below spill edge, ρ is air density at ambient condition, C_p is specific heat, T is absolute temperature and g is gravity acceleration.

Validation and Results:

The First step in this study is to perform model validation against Ho [5] results. The description of all simulations and comparison of severity of smoke contamination of present research with past research [5] is shown in Table 1. It is found that the results are in a reasonable agreement with Ho's results. For validation, twelve cases are investigated and modeled which were presented by Ho to investigate smoke contamination occurrence in different balconies. The severity of smoke contamination in each balcony is defined at three levels which are clear, shallow and deep smoke layer as in Table 1. The same criteria (smoke severity) have been used by Tan and Ho [3-4] to differentiate the extent of smoke contamination.

Table 1: Comparison of smoke severity.

	Dimensions			Ho Research [4]					Present Research				
				Balconies					Balconies				
case	b (m)	w (m)	HRR (KW)	1	2	3	4	5	1	2	3	4	5
1	5	10	1581	•	••	••	••	••	•	••	••	••	••
2	5	10	3162	•	••	••	••	••	••	••	••	••	••
3	5	6	4746	•	•	••	••	••	•	•	••	••	••
4	5	2	1581	O	O	O	O	•	O	O	O	O	•
5	3	8	1581	••	••	••	••	••	••	••	••	••	••
6	3	6	3162	•	••	••	••	••	•	••	••	••	••
7	3	4	4746	O	•	•	••	••	O	•	•	••	••
8	2	6	3162	•	••	••	••	••	•	••	••	••	••
9	2	4	3162	•	•	••	••	••	•	•	••	••	••
10	2	2	1581	O	O	•	•	••	O	O	•	•	••
11	1.5	4	3162	•	••	••	••	••	O	•	••	••	••
12	1.5	2	4746	O	O	•	••	••	O	O	•	••	••

Smoke contamination		Present	Ho
	Clear	O	O
	shallow	•	•
	deep	••	••

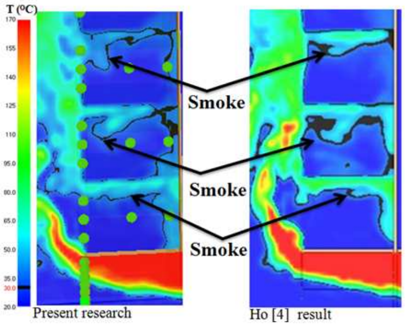
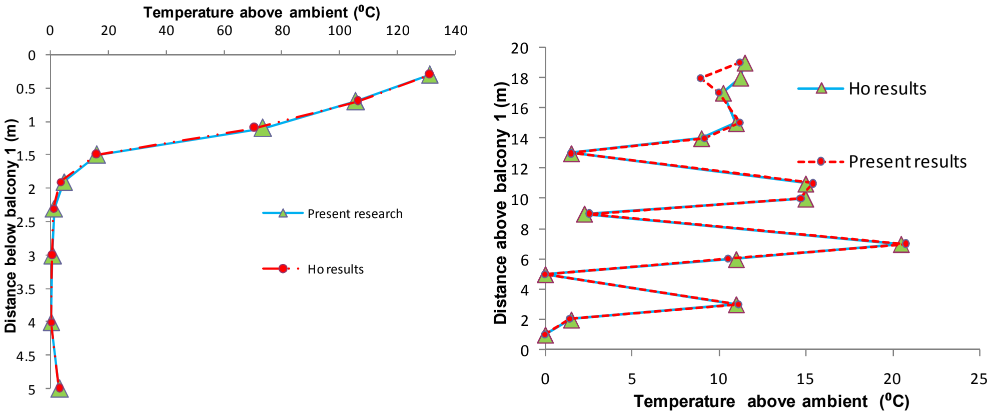


Fig. 2: Comparison of temperature distribution.

The results of case 2, (shown in Table 1) are selected in this paper as an example to show the validation process performed in this paper. In the temperature contour, the black color represents temperature of 30°C which is 10°C above ambient temperature as shown in Fig. 2. Past research [4] found that contamination occurred when the temperature difference in the balcony reached 10°C above ambient. The black spots or regions in the temperature contours in the balcony show that smoke is present in the balcony. The temperature contours presented in Fig. 2 shows that the simulation results of the model developed in this research is in reasonable agreement with Ho's contour. Table 1 and Fig. 3 show the comparison of the results obtained from this research with the results recorded by Ho. Fig. 3 shows that the temperature recorded at balcony 1 and temperature at the edge of each balcony.



(a) (b)

Fig. 3: (a) Temperature below balcony 1 and (b) Temperature above balcony 1.

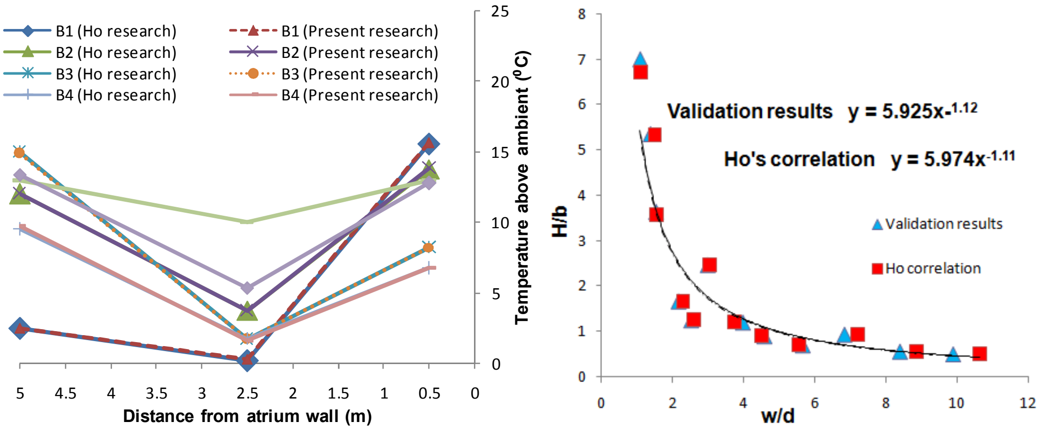
Similarly, Fig. 4 (a) shows the temperature in the middle of each balcony are also similar to Ho's results. In Fig. 4(b) the correlation developed by Ho to predict the height of smoke contamination occurrence is presented. The correlation has parameters including smoke contamination height above balcony 1, *H* depth of smoke layer, *d* and balcony breath, *b*. Depth of smoke layer below spill edge is used in the correlation and it is obtained by using smoke layer height device which is available in FDS software. The correlation obtained by Ho for smoke contamination is shown in Eq. 3. The correlation shown in Eq. 4, is the validation of this research model against Ho's correlation. As seen that the results recorded (Table 1, Figs 2,3 and 4) in this study and related correlations (Eqs. 3 and 4) are in good agreement with Ho results.

$$Y = 5.974X^{-1.11} \tag{3}$$

$$Y = 5.925X^{-1.12} \tag{4}$$

Where, Y = H/b and X = w/d

Both X and Y are dimensionless numbers.



(a) (b)

Fig. 4 (a) Temperature in each balcony and (b) Correlation for validation without down stand

Effect of Down Stand:

Following the validation, the model developed in this study is then used to investigate the effect of down stand structure at fire compartment opening on smoke contamination. Down stand structure is introduced in this model as shown in Fig. 1. As shown in the table 1 that when the down stand structure is introduced at the fire compartment opening, the extent of smoke contamination in each balcony is increased. It shows that the presence of 1m deep down stand resulted in increasing smoke spread in upper balconies of atrium. Fig. 5 shows that the presence of down stand structure gave completely different correlation as compared to Ho's correlation which shows that presence of down stand structure has significant effect on smoke behavior and contamination occurrence. The correlation developed in this research (presence of down stand structure) is shown in Eq. 5, based on the results recorded when the down stand is introduced.

$$Y = 2.645X^{-0.93} \tag{5}$$

Comparison between the results recorded and the correlation developed in this research when down stand structure is introduced (Table 2 and Fig. 5) with results recorded and the correlation developed by Ho [5] showed that the presence of down stand structure resulted in a significant increase in smoke contamination.

Table 2: Comparison of smoke contamination

Dimension			No down-stand					with down-stand				
			Balconies					Balconies				
b (m)	w (m)	HRR (KW)	1	2	3	4	5	1	2	3	4	5
5	10	1581	•	••	••	••	••	••	••	••	••	••
5	10	3162	••	••	••	••	••	••	••	••	••	••
5	6	4746	•	•	••	••	••	•	••	••	••	••
5	2	1581	O	O	O	O	•	O	•	•	•	•
3	8	1581	••	••	••	••	••	••	••	••	••	••
3	6	3162	•	••	••	••	••	••	••	••	••	••
3	4	4746	O	•	•	••	••	•	•	••	••	••
2	6	3162	•	••	••	••	••	••	••	••	••	••
2	4	3162	•	•	••	••	••	•	••	••	••	••
2	2	1581	O	O	•	•	••	O	•	•	•	••
1.5	4	3162	O	•	••	••	••	•	•	••	••	••
1.5	2	4746	O	O	•	••	••	•	•	••	••	••
Smoke contamination			No down-stand					With down-stand				
		Clear	O					O				
		shallow	•					•				
		deep	••					••				

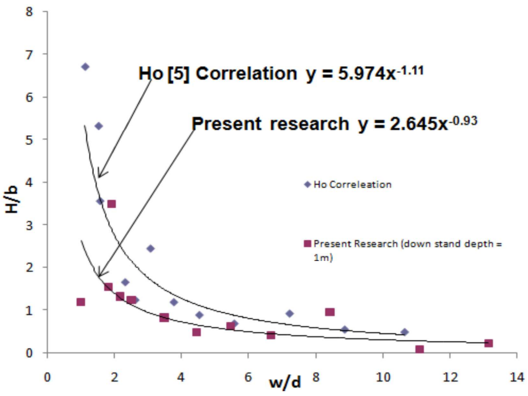


Fig. 5: Correlation in presence of down stand.

Conclusion:

Past research has not studied the effect of down stand structure at fire compartment opening on smoke contamination in upper balconies of the atrium. Therefore this research investigates this by using CFD software FDS version 5. From the simulation results, a correlation has been developed to predict smoke contamination occurrence in upper balconies. This correlation showed that the presence of 1m depth down stand in fire compartment exit has a strong effect on smoke spread in upper balconies and resulted in increasing the spread of smoke contamination in atrium upper floors.

Acknowledgement

The authors would like to acknowledge Universiti Teknologi Petronas for providing financial assistance under Graduate Assistance Scheme.

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