

Smoke dispersion in a building with double-skin facade

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Abstract: Increasingly Double-Skin Façade (DSF) structure has been applied in new buildings since 1970s, as it potentially offers many environmental benefits, such as solar control, noise abatement, thermal flue and day lighting control. One of the functions that the structure can perform is to provide natural ventilation. Many such façade structures therefore have no horizontal separation within the cavity. While this design accelerates the airflow within the shaft, it also raises a concern of smoke propagation between storeys in a fire event. Furthermore, the time of smoke fill up the building compartment can be associated with the safety escape time of occupants. This study investigates the process of smoke filling in rooms connected by the DSF system. A computational fluid dynamics (CFD) model was developed to simulate the progressive dispersion of smoke in its early development. The model was validated by a full size fire test data and a salt-water experiment. The model is then used to test a number of DSF designs commonly seen in industry. Running the models under various scenarios will allow the escape time, the key fire safety parameter, to be examined with a number of key design parameters. This will then improve DSF design with better fire safety features.

Keywords: double-skin façade structure; CFD mode; DSF design

1. Introduction

The concept of ecological buildings, which considers optimising the energy usage and sustainable development of the building by the best combinations of the ambient natural environment, has been rapidly applied in building design since 1970s. Several new improvements have been made to the building elements to achieve this goal. Façade, one of the key elements in every aspect from aesthetic to functional in a building, certainly plays an important role in this concept. Adding an additional transparent façade layer to a curtain wall was originally a remedial solution to the problems associated with the transparent wall structure, such as excessive solar gain, infiltration of cold air and rainwater, high noise transmission and high thermal transmittance (U-value). This improved façade structure, which is normally called double-skin façade (DSF) nowadays enhances the building envelope to gain a more protection from the outdoor weather and better control of the indoor environment.

A basic DSF unit is constructed by the five elements: the outer façade layer, the inner façade layer, the top vent, the bottom vent and the solar shading device (Fig 1). The cavity between the outer and inner layers has many roles to play, from acting as a buffer zone between the outdoor climate and indoor environment and serving as a vertical thermal flue for air ventilation

to accommodating the solar shading device and providing access to maintenance of the façade system, when the cavity is wide enough. After decades of evolution, there are various types of DSF have been designed and each of those is constructed to solve one or more problems and perform certain functions. The various DSF can be categorised into three types¹ by how the horizontal separations are devised in the cavity: single-floored, or full-height or hybrid, combining the both.

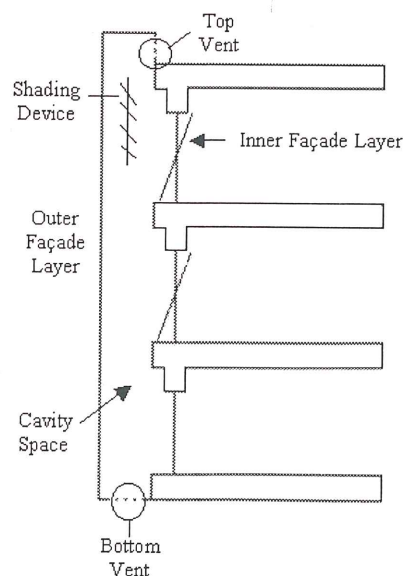


Fig. 1. The structure of double-skin façade

As many DSF structures were made for provision of

natural ventilation without loss much protection of outdoor weathers, there are no horizontal separations as blockage in the cavity space, the airflow could therefore travel freely in this vertical passage from one floor to another²⁻⁴. This configuration is certainly beneficial from enhance air movement point of view, but it also raised a serious concern in fire safety, In the event of a fire, smoke, which include heat, variety of toxic and non-toxic gases would be drawn into the cavity and dispersion within to vertical channel by following exactly the same path as the air in the natural ventilation process but with much greater force. Due to both lack of vision and reduction of oxygen, the great volume of smoke will make escape difficult for the occupants in the building from the fire. Therefore the need to control the movement of smoke is a significant issue for fire safety. Similar to the cavity in the DSF, the atrium has the same safety problem and has attracted many research attentions in this field⁵⁻⁹. As an atrium has a much greater space volume than a DSF, the atrium can provide a huge reservoir for smoke and allows a longer time for excavation of occupants than a DSF. It seems that DSF fire safety should receive more research interests. Ironically the preliminary literature search carried out in this study found no such existence.

2. Method

The objective of this study was to investigate the process of smoke filling in rooms connected by a full height DSF system in a simple but typical low rise building.

The computational fluid dynamics (CFD) modelling technique was adopted to predict the transient fire spreading and smoke movement for building of different purpose. As the CFD modelling has the ability to predict the smoke behaviour within an enclosure of a complex geometry, it was adopted for this study to develop a computer model building with a DSF structure. The model was used to simulate a number of scenarios designed to test some DSF features and operations commonly seen in practise. In particular, the influence of the width of cavity to the smoke movement in a DSF building was examined. The investigation was made a complete run of modelling in two stages: Firstly, simulation started with a thermal

dynamical simulation for the building with the DSF operating for a certain weather conditions. The simulation calculated the airflow rates in all major paths, heat fluxes at main surfaces and temperature in all spaces and surfaces. This was done by using a thermal dynamical modelling package, TAS. These data were then used to set the initial conditions for the CFD smoke simulation in the second stage, and that modelling could visualise the development of the fire and dispersion of smoke in the DSF and rooms.

2.1 Conceptual model building

The conceptual building modelled in this study was derived from Helicon Buildings with DSF reviewed in a previous study¹⁰. It was a five-storey tower block office building, in which there were ten cellular offices on each floor, five rooms on the north side and five on the south separated by a central corridor. These offices were all at the same size: $5 \times 3.6 \times 3.5 \text{ m}^3$. A full-height DSF was to the south-facing façade. At the top and the bottom of the cavity there were two operable vents, each had an open area of $1.6 \times 0.6 \text{ m}^2$.

In practice various widths are applied in designs. This design parameter, along with a number of others affects thermal performance of the DSF, including how airflow behaves in the façade cavity. Therefore it affects smoke dispersion in the even of fire. In this paper, 4 façade structures with differing widths of were modelled.

2.2 Computational fluid dynamics (CFD) modelling

A CFD model was developed to simulate the progressive dispersion of smoke in its early development. The CFD package used in this study was Fire Dynamic Simulator (FDS), which was developed by National Institute of Standards and Technology (NIST) ¹². The model has been validated by a full size fire test data and a salt-water experiment¹⁷. Running the models under various scenarios will allow the escape time, the key fire safety parameter, to be examined with a number of key design parameters. This will then improve DSF design with better fire safety features.

2.2.1 Domain and model geometry creation

Fig. 2 shows the configurations of the model

building whose dimensions are listed in Table 1. The size of the domain is 6 m, 3.6 m and 18.5 m in x , y , and z directions of a Cartesian coordinate system, respectively. The width of cavity was fixed in 9 different dimensions: 0.2, 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.4 and 1.5 m

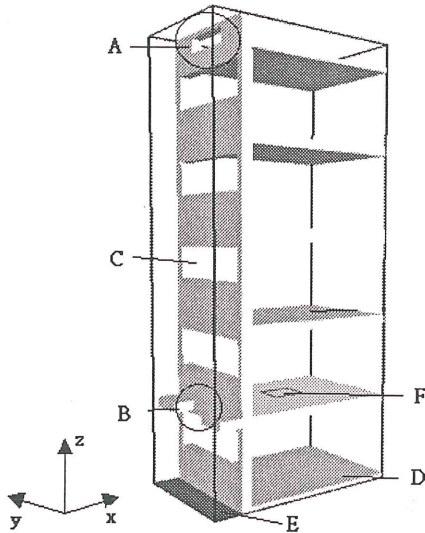


Fig. 2. Geometry and dimensions of modelling building

Table 1 Dimensions of modelling building in metres

	Depth x	Width y	Height z
A: Top Vent	---	1.6	0.6
B: Bottom Vent	---	1.6	0.6
C: Window Opening	---	3.2	1.4
D: Floor Area	5.0	3.6	---
E: Cavity Space	---	3.6	15.0
F: Fire Source	1.0	0.8	---
Domain Size	6.0	3.6	18.5
Height of Each Floor	---	---	3.5

2.2.2 Mesh generation

54×27×108 hexahedral structural grids were generated to disperse the computational model domain.

2.2.3 Numerical model set up

The CFD model included a full set of conservation equations for the mass, momentum, energy and species plus the equation of gas state¹². Large Eddy Simulation (LES)¹³ was adopted as the turbulence model.

In order to set the initial condition for CFD smoke modelling, a thermal dynamic modelling software TAS was used¹⁴. According to the TAS prediction, for the cold season operation, the outdoor dry bulb temperature was 7.2°C, and the temperatures in the

cavity and the room were all around 20°C. The initial pressure was 101 325 Pas. The wall boundary condition was assume to be adiabatic expect the outer façade layer. The outer glass façade was defined as a thermally thin solid wall and the surface temperature was updated at each time step according to the following equation.

$$\frac{dT_s}{dt} = \frac{q_c'' + q_r'' - q_{rr}''}{\rho_s c_s \delta} \quad (1)$$

where T_s is the wall temperature, q_c'' , q_r'' , q_{rr}'' are the convective, radiative and re-radiative fluxes at the surface.

The input ρ density was 2700 (kg·m⁻³), the specific heat c_s was 0.057 (kJ·kg⁻¹·K⁻¹) and thickness δ of wall was 0.2m. A fire of 1×0.8 m² was located at the centre of the room on the ground in the first floor. The hear release rate was kept constant at 1 MW·m⁻². The time step was 1 s and the duration simulated was 500 s.

2.3 Study assumptions

Several assumptions were made during the model simulation and result analysis in this study:

- 1) There were no smoke detectors and sprinklers in operation;
- 2) The parameter of escape time was taken into examination. The escape time was defined as the time difference between the times while building occupant would realise a fire (detection time) and the time to danger¹⁵.
- 3) The building occupants could only sense the smoke by either smelling the smoke or seeing the smoke via the window. Therefore the detection time was defined as the time when the occupants first seeing smoke via the window.
- 4) The time to danger was considered as while the height of clear layer is less then 3 metres¹⁶. Because the visibility would be decreased and the oxygen would be reduced in such a condition. This would make escaping from the fire more difficult for the occupants.
- 5) The top and bottom vents were sealed to reduce the heat loss from the indoor environment to the outdoor, which could be considered as the DSF operating in a winter season.
- 6) The heat release rate remained constant in all the cases.

3. Result and discussion

The out put data of the model simulation are summarised in Table 2. Where the detective time, time to danger and escape for each floors has shown while the width of the cavity equal to 0.4, 0.6, 1.0 and 1.5 m.

Table2. data of the model simulation

Width of Cavity Space /m	Floor	Detective Time /s	Time to Danger /s	Escape Time /s
0.4	2 nd	2	17	15
	3 rd	4	19	15
	4 th	8	25	17
0.6	2 nd	4	20	16
	3 rd	6	21	15
	4 th	14	29	15
1.0	2 nd	6	20	14
	3 rd	12	26	14
	4 th	18	31	13
1.5	2 nd	10	24	14
	3 rd	14	28	14
	4 th	18	36	18

Fig. 3 shows the tendency diagrams of the width of cavity (x-direction) and the detective time (a), time to danger (b) and escape time (c) of the occupants.

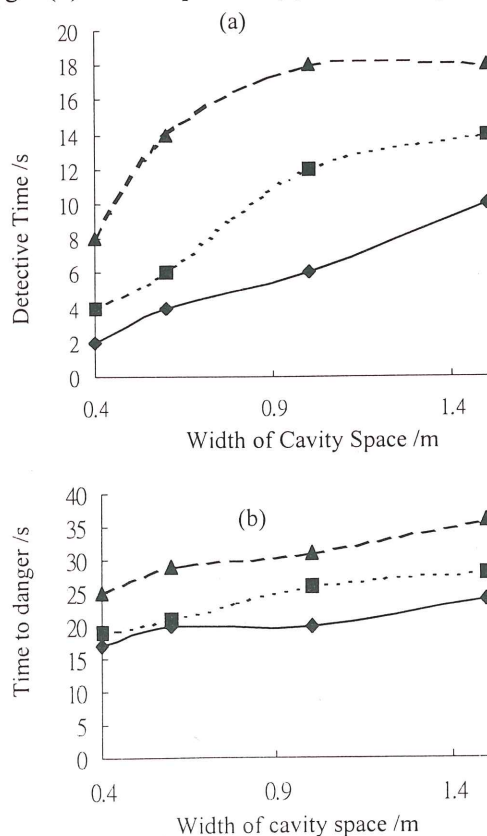
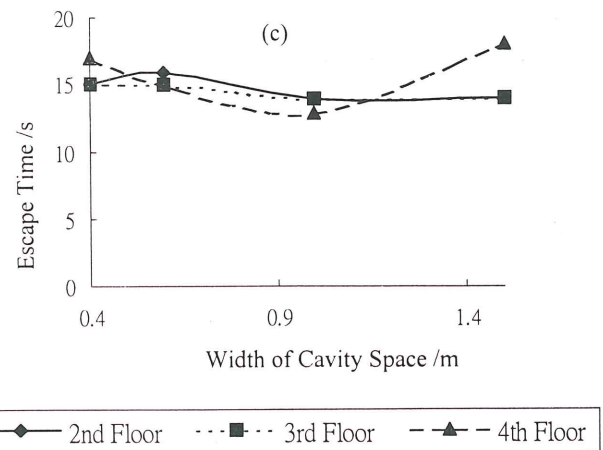


Fig. 3. Diagram of Width-Time: (a) Detective time; (b) Time to danger; and (c) Escape time

The influence of the width of cavity on smoke movement in a building can be observed from the output data, which was shown above:

1) In the case of the width of cavity equal to 0.4 metres, the smoke movement in the cavity was very fast. After fire ignition, the smoke rose up and fulfils the upper zone of the room where the fire source was located and started to disperse to the cavity. Due to the large volume of the fire generated heat-flow and the frictions of the surface of facades, smoke was forced into the first floor, the second, the third floor and the top vent area respectively. The smoke can be sensed as soon as in two seconds, almost immediately after the ignition and to reach the time to danger is also shorter than other wider façade structure.

2) While the width of cavity equal to 0.6 metres and 1.0 metre, the smoke was firstly move into the cavity and then part of smoke were flow into the first floor and part of smoke were continuing rise up along the cavity. This amount of smoke then partially moved into the second floor and the others moved to the zone of top-vent and then press down to the third floor.

3) When the cavity equal to 1.5 metres, the smoke after escaping from the ground floor was gathered at the bottom cavity and then rose up to the top zone. After the whole cavity was fulfilled, the smoke then flow into each floors.

4) It has also been observed that the escape time for all size of cavity were actually very similar around 14 seconds to 18 seconds.

4. Conclusions

This study on smoke dispersion in a double-skin façade building draws the following conclusions:

1) Validated by a purposely designed salt-water experiment with the same structure, the CFD model simulated satisfactorily the smoke dispersion in a building with multiple zones, including a naturally ventilated zone.

2) Three different widths of cavity were examined to observe the movement of smoke within an enclosure in a fire even.

3) Although the results of the detective time and the time to danger were changed from one case to another, the maximum difference of the escape time was only four seconds. The escape times for the occupants are short. Therefore, in DSF building, to install a passive smoke control system to extend the escape time of building occupants would be crucially important.

4) More design parameters, such as the height of the façade cavity, the size of the room that affect the volume of smoke reservoir, etc. need to be further examined to gain a better understanding of smoke dispersion in this structure.

5) As many approximations were made, the CFD simulation could only predict the tendency of the fire and smoke movement. The accuracy is uncertain. Moreover, the behavior of fire and smoke within an enclosure is a extremely complicated issue. A full-scale real fire test in the DSF structure would be very much helpful as according to the pervious review of literatures there were only a few real fire tests done in such structure.

6) As the conclusion of this study, the full height type DSF system presents a high risk of safety in the event of a fire and more attention in fire safety is needed in this structure. More studies are needed to gain better understanding of this matter and make best use of this structure in environmental buildings.

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