Numerical study of effects of wind on the vertical fire spread with vertical/horizontal spandrel

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Abstract

Due to the importance of preventing the vertical fire spreading along with buildings, two fire inhibition methods were raised by the National Construction Code clause [1] C2.6(a) including vertical spandrel of at least 900 mm high or horizontal spandrel of at least 1100 mm deep. This project aims to answer the research question of whether vertical spandrel of 900 mm and horizontal construction of 1100 mm are equivalent in performance in inhibiting the vertical fire spreading under the effects of wind using fire dynamics simulator (FDS) simulations. The geometry of the simulations is modified from experimental works conducted by Oleszkiewicz [2] by adding an air opening on the back wall. The preliminary results show that by slightly increasing the front wind (the wind direction is normal to the front opening of the building) from 0 m/s to 0.5 m/s, the radiation heat transfer from the flame to the above floor is increased slightly, however, further increasing the front wind speed will reduce the radiative heat flux on the above floor, due to the blocking effect of the front wind. When the front wind speed increases to above 4 m/s, the flame is blocked within the room. When the side wind (the wind direction is parallel to the front opening of the building) is introduced, there is a slight increase in heat flux for the wind speed of 1~4 m/s. Based on the preliminary simulation results, it is found that for the wind conditions, fire load and building structure investigated in the paper, the performance of the 900 mm vertical spandrel is lower than the horizontal spandrels even for the horizontal spandrel of 500 mm.

Introduction

During numerous fire accidents within constructed buildings, hot smoke that was emitted from openings such as windows/doors of the incident floor can cause above floors to be inflamed as well. When the room on fire is under-ventilated, the fire caused by the unburned fuel will destroy the windows openings and spread along the exterior walls, and once the heat flux is sufficient enough, the flame height could exceed floor heights causing subsequent fire to spread between floors which will lead to significant damage to properties and loss of lives [4]. Therefore, preventing the vertical spreading of fire between floors via openings has been a major aspect of fire safety engineering [5]. As described in National Construction Code (NCC) clause C2.6(a) [1], there would be two possible approaches to preventing vertical fire spread. One of these two approaches is using a vertical spandrel of more than 900 mm in height. And the second approach is adding a horizontal construction which needs to project at least 450 mm beyond the openings with a minimum depth of 1100 mm. NCC implies that those two options are alternatives to each other in terms of their efficacy in inhibiting fire spread. The previous study on the clauses using the computational fluid dynamics (CFD) code FDS simulations from [6] suggests that horizontal projection has better fire inhibition performance than vertical spandrel. However, the authors of [6] only conducted the investigation based on a single defined opening geometry and three different heat release rates without consideration of the effect of other parameters, such as outdoor winds. Other similar papers analysing the performance of protection methods such as [7-11] also have significant limitations in their scope. Consequently, it becomes crucial for this project to understand the effect of outdoor winds on the fire inhibition performance difference between horizontal construction and vertical spandrel. This conclusion on the performance of fire inhibition methods could then potentially be used to verify the consistency of existing building code and even act as a guideline for future fire inhibition methods applied for multistorey buildings.

This paper reports the preliminary results of the research on the performance of the vertical spandrel and the horizontal construction based on the Australia NCC requirement in inhibiting the vertical fire spreading under outdoor winds using fire dynamics simulator (FDS) simulations.

Numerical methods and processes

For this project, FDS version 6.7.7 [12] with Pyrosim pre-processor [13] is employed. According to the technical guide from [14], FDS solves the Naiver-Stokes equations to compute flow fields. Additionally, large eddy simulation (LES) is utilised to handle turbulence.

The computation domain, which is modified from the experimental geometry described in [2] and simulation geometry elaborated in [11] is modeled in Pyrosim as shown in Figure 1. Please note that different from the geometry in [2], in this project, an additional air intake with dimensions of 5.4 m x 0.8 m is included at the back of the ground floor to ensure that there would be sufficient air supply throughout the simulation. The domain has an overall size of 7.2 m x 11.2 m x 10.8 m whilst the construction locates in the middle of the domain has the dimensions of 6.4 m x 4.8 m x 10.4 m. The dimension of the domain was made sufficient for the plume to spread beyond the openings. The opening is located in the negative y-axis direction. The front opening for the ground floor has a dimension of 1.0 m x 2.7 m whilst regions above the front opening are sealed off for measurement. An additional air intake with dimensions of 5.4 m x 0.8 m is included at the back of the ground floor to ensure that there would be sufficient air supply throughout the simulation. The thickness of the walls is defined as 0.1 m. The fire source is placed at the center of the room with a surface area of 9 m^2. The height of the vertical spandrel is defined as 0.9 m. The depth of the horizontal construction is varied between 0.5 m and 1.3 m for parametric analysis. The full range of horizontal construction dimensions included for this project are described in table 1.

In terms of meshing, a mesh size of 0.1 m is applied for the entire domain which leads to fine mesh resolution according to [13]. The mesh has a D*/dx ratio of approximately 22 which is slightly larger than the suggested value of ≥20 from Pyrosim [13].

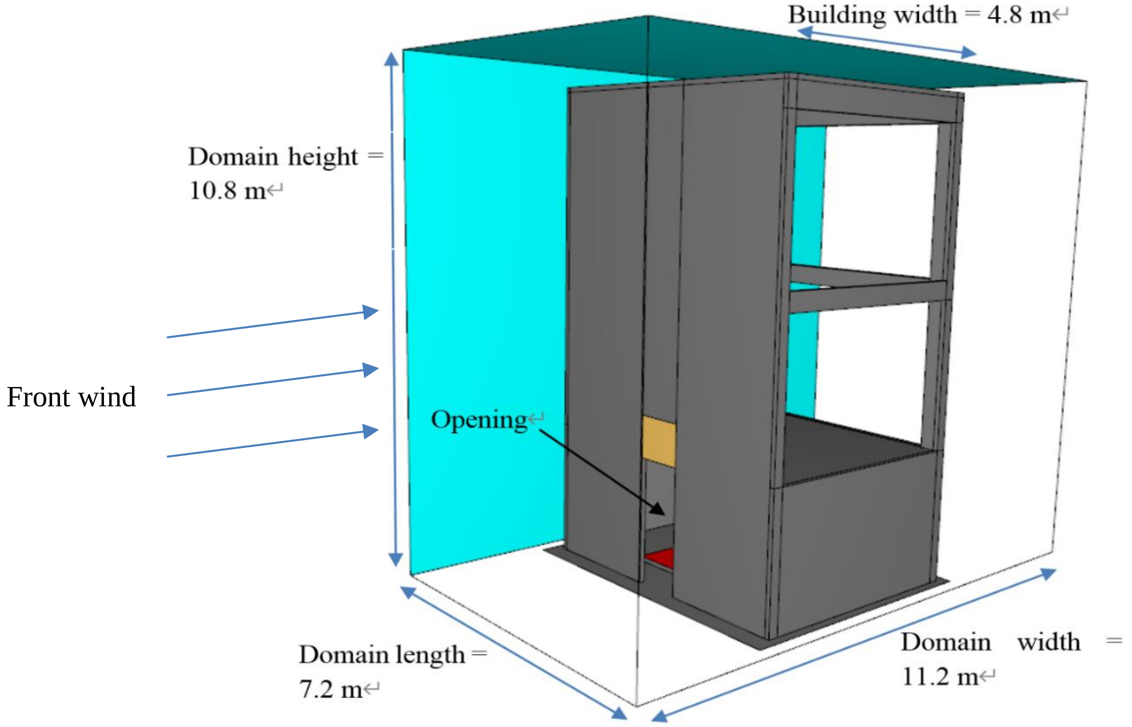


Figure 1 (a): Overall domain for FDS simulation

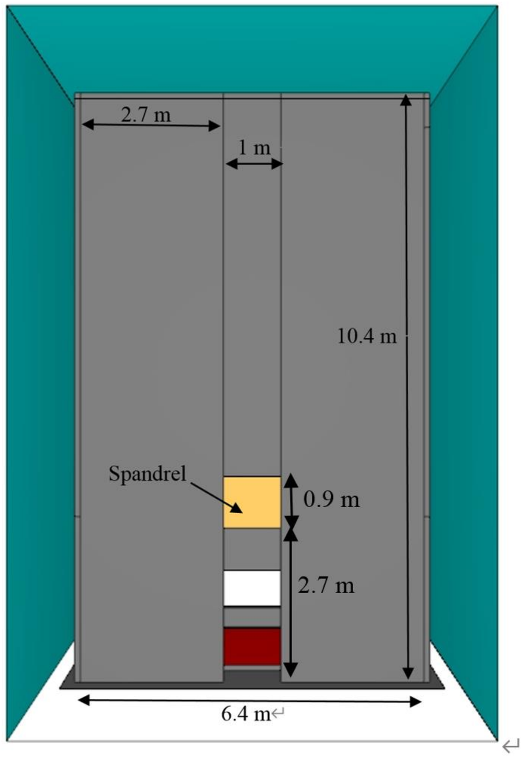


Figure 1 (b): Front view of computational domain with 0.9 m vertical spandrel

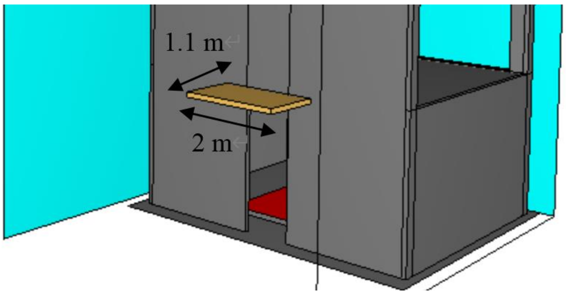


Figure 1 (c): Computational domain with 1.1 m horizontal spandrel

For the boundary conditions, the six boundary surfaces of the overall mesh domain are modeled as vents which essentially act as openings to allow air to flow in and out of the domain. For the cases that include outdoor wind, the wind inlet is modelled as an air supply with a designated wind speed. The inert boundary condition is then applied for the spandrels included in the geometry which represents a smooth wall with fixed ambient temperature and emissivity of 0.9. The rest of the walls are defined as concrete walls. For the heat release rate of the burner, a constant total release rate per unit area of 900 kW/m^2 is used. This results in an average heat release rate of 8.1 MW which is roughly maintained after the fire is fully developed. The fire will last for 1800s.

Since this project aims to explore the effect of wind parameters, supply surface boundary conditions are applied at the inlet surface with designated flow speed. The variation of wind parameters included is described in Table 1. In Table 1, for wind direction, ‘Front’ means the wind direction is normal to the front opening of the building, while ‘Side’ means the wind direction is parallel to the front opening of the building.

Table 1: Parameters investigated in the simulations.

Horizontal Spandrel Size (m)	Wind direction	Wind speed (m/s)
1.3, 1.1, 0.9, 0.7, 0.5	Front, Side	0.25, 0.5, 0.75, 1, 2, 3, 4, 5

Results and discussion

From Figure 2, it is evident that under the front wind of 1 m/s, the 0.9 m vertical spandrel has higher incident heat flux values on the above wall than those of the horizontal cases, indicating a lower performance in terms of preventing the vertical fire spread. Additionally, increasing the horizontal construction length would lead to better protection performance as well. As shown in Figure 3, by slightly increasing the front wind from 0 s/m to 0.5 m/s, the radiation heat transfer from the flame to the above floor is increased slightly. In other words, low front wind speeds (up to 0.5 m/s in this case) would reduce the effectiveness of the protection methods. However, for front winds with a speed over 1 m/s, increasing the wind speed would be beneficial in preventing vertical fire spread instead, as the heat flux values on the above wall decrease with increasing wind speed until it reaches a constant value of 0.43 kW/m^2. Among the analysed protection methods shown in Figure 3, for low wind speeds up to 3 m/s, the 1.1 m horizontal projection is more efficient in preventing fire spread than the other protection methods due to its lowest predicted heat flux received at the external wall of the above level.

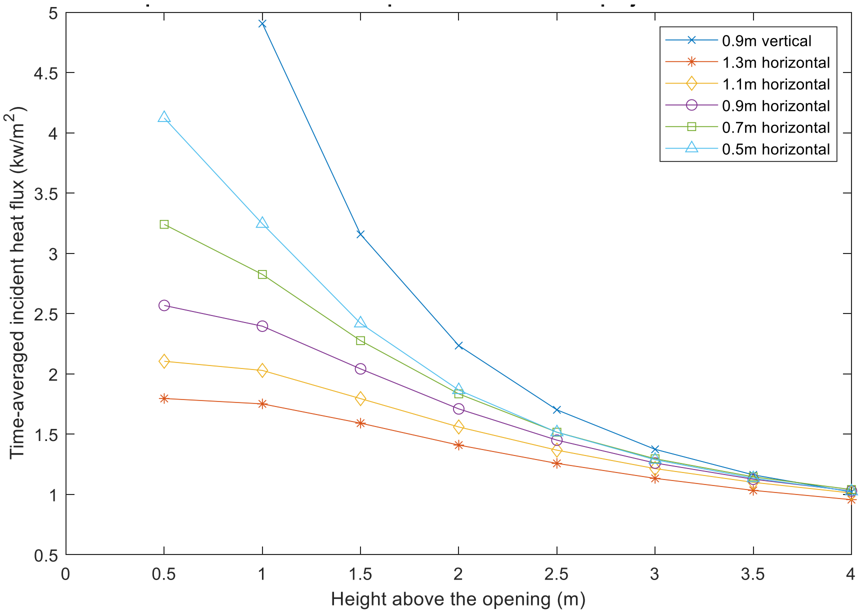


Figure 2: Performance comparison between horizontal construction and vertical spandrel for the 1 m/s front wind

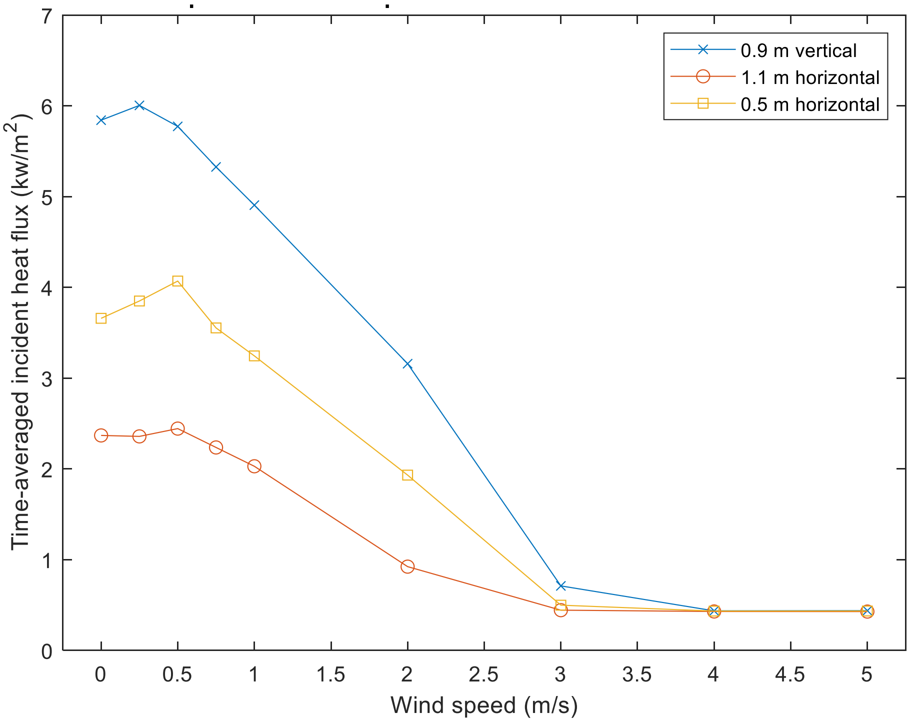


Figure 3: Performance comparison between horizontal construction and vertical spandrel for the front wind with various speeds

Temperature plots for 1.1 m horizontal construction are employed to explore the effect of increasing front wind speed on the performance of protection methods. As shown in Figure 4, by slightly increasing the front wind up to 0.5 m/s, the front wind (from the left-hand side of the figure) pushes the flame (which is indicated by the high-temperature zone) above the horizontal construction toward the right-hand side, leading to radiation heat transfer from the flame to the above floor increased slightly. As the wind speed increases further to 1 m/s, the flame is pushed back toward the opening below the horizontal construction, decreasing the radiation on the above wall as shown in Figure 3. When the outdoor wind speed increase to 3 m/s, the high-temperature region of over 500 °C is nearly blocked under the horizontal construction. Eventually, when the front wind increases to 5 m/s, the flame is completed blocked within the room, which justifies the lowest heat flux recorded in such conditions as shown in Figure 3.

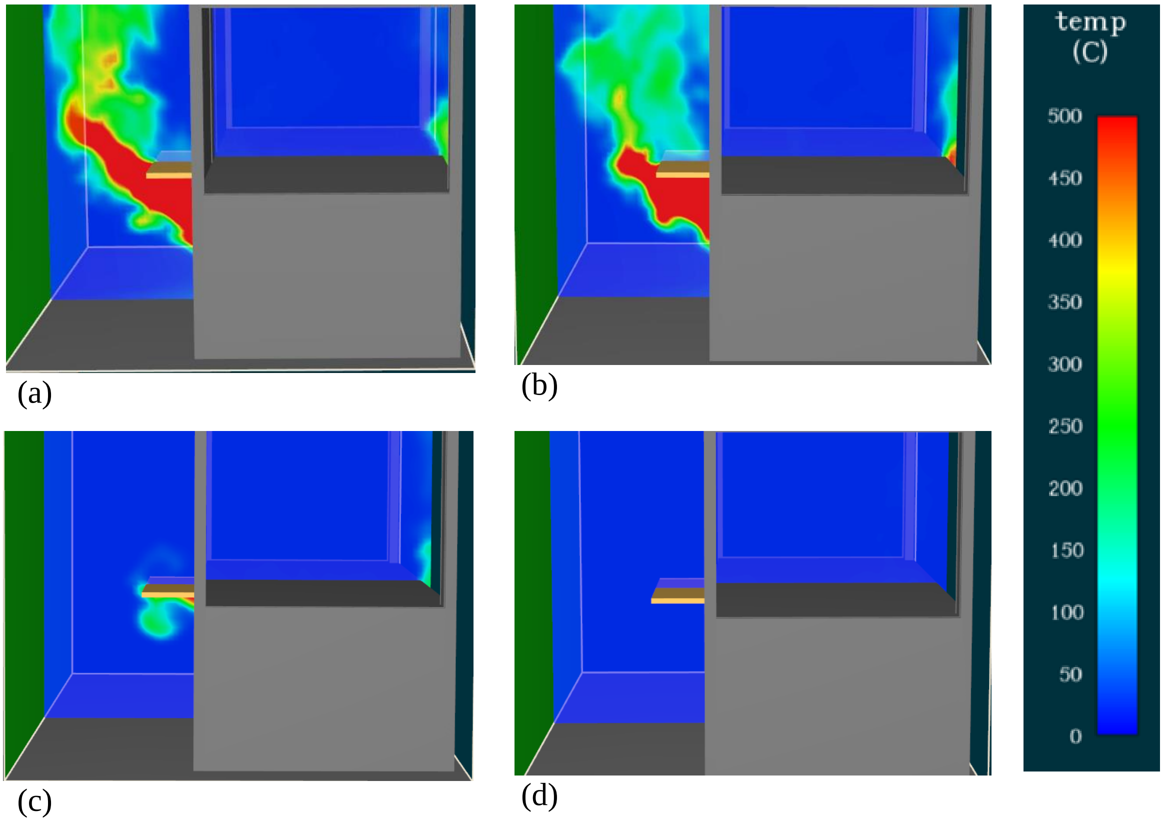
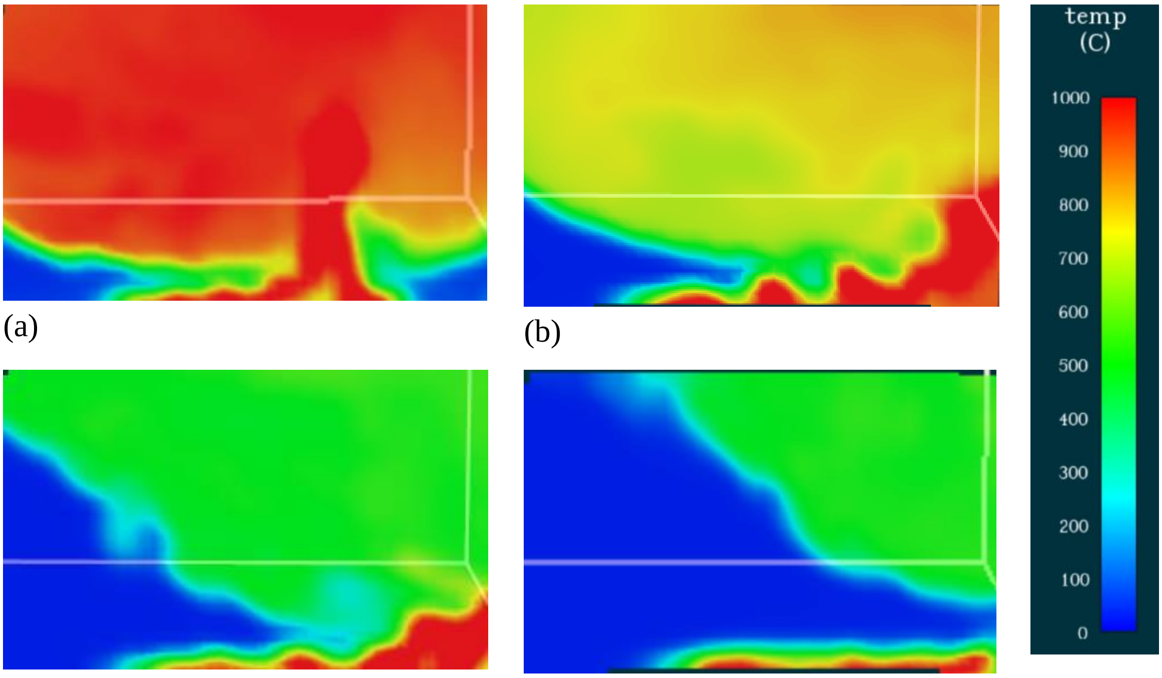


Figure 4: External Temperature plots for 1.1 m horizontal construction with different front wind speed (a) 0.5 m/s, (b) 1 m/s, (c) 3 m/s, (d) 5 m/s.

Temperature contours for spaces inside the structure are plotted to further develop the conjecture. As shown in Figure 5, at a lower front wind speed of 0.5 m/s, the flame travels vertically and then circulates around the ceiling. As the front wind speed increases to 2 m/s – 5 m/s, high-temperature zones near the ground are pushed away towards the rear ventilation slot (the right-hand side of the figure), leading to the lower temperature being experienced at the front wall. Additionally, more outdoor air at 20 °C is introduced to the room at a higher wind speed, cooling down the room.

In terms of the cases with a side wind, as shown in Figure 6, similar to the normal wind cases, the side wind with lower speeds would compromise the performance of protection methods as the heat flux values on the above wall are higher than those of heat flux with 0 m/s side wall. Additionally, increasing side wind speed from 3 m/s to 5 m/s, in this case, is beneficial for inhibiting vertical fire spread. However, unlike the previous cases, there is not a significant performance difference between the cases with 5 m/s side wind and the cases with 0 m/s side wind. In terms of differences between protection methods, fluctuation in heat flux for vertical spandrel is the most severe out of all protection methods which indicates its protection capability is the most affected by the side wind out of all protection methods investigated. Interestingly, there are abrupt changes in the heat flux for the vertical spandrel case of 1 m/s shown in Figure 6. The causes of the high heat flux on the above wall are still unknown and are under investigation. Nevertheless, it does not affect the general trends and findings of the side wind cases reported in the paper.



(a) (b) (c) (d)

Figure 5: Internal temperature plots for 1.1 m horizontal construction with different front wind speed (a) 0.5 m/s, (b) 2 m/s, (c) 3 m/s, (d) 5 m/s

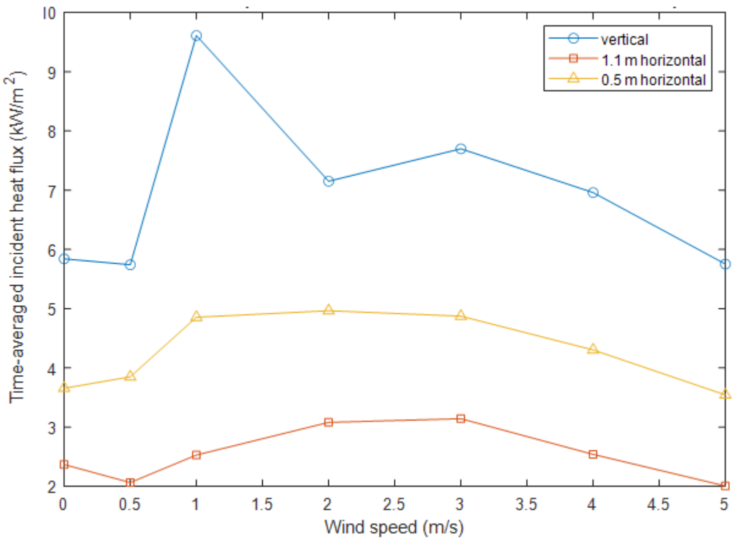


Figure 6: Performance comparison between horizontal construction and vertical spandrel for side winds with various speeds

Conclusions & Future work

Based on the preliminary results, it is found that for the wind conditions (both the front wind and side wind conditions), fire load and building structure investigated in the paper, the performance of the 0.9 m vertical spandrel in preventing vertical fire spread is lower than the horizontal spandrels even for the horizontal spandrel of 0.5 m.

By increasing the front wind from 0 m/s to 0.5 m/s, the radiation heat transfer from the flame to the outdoor wall surface above the opening is increased slightly, however, further increasing the front wind speed will reduce the radiative heat flux on the above floor, due to the blocking effect of the front wind. When the front wind speed increases to above 4 m/s, the flame is blocked within the room. Meanwhile, the changes in heat flux on the outdoor wall above the opening are much less significant for the various side wind speeds from 0 m/s to 5 m/s, partially due to the less significant blocking effects. Nevertheless, these results are only applicable to the investigated conditions.

As part of future work, more simulations need to be run to establish systematic conclusions on performance comparison based on the exact minimal dimensions suggested by NCC clauses. Further efforts will be put into parametric studies where the effect of fire size, opening size, wind speed, and other environmental parameters will be accounted for. Eventually, as the final objective of the project, the simulation model will be applied to real-life scenarios.

Acknowledgments

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