Fire Science – Dr Ezekoye

CFAST Project

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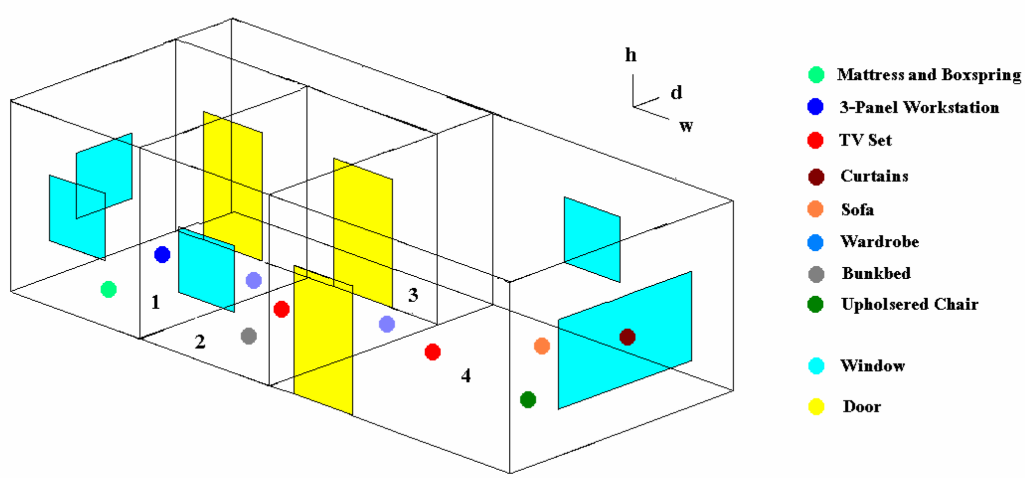
Background

Analytical models for predicting fire behavior have been evolving for decades. Three specific types of models used to predict fire behavior include zone models, network models and field models. Each type of model has advantages and disadvantages. Network models and field models are more precise and more detailed than zone models. However, they require far greater run times than zone models. Network models and field models are used when a detailed prediction of the flow is of primary concern (CFAST Manual). The zone model can produce a fairly realistic simulation of fire behavior under many common and important conditions in minutes. Zone models assume that each compartment can be broken into a small number of control volumes, each of which is internally uniform in temperature and concentration. Thus, we used the zone model Consolidated Fire and Smoke Transport (CFAST) to predict the fire behavior in a two-bedroom apartment. CFAST is governed by equations for conservation of mass and energy and is usually accurate within approximately 10 to 25 percent (CFAST Manual). It breaks compartments up into two zones (an upper layer and a lower layer). The fire generates a plume that carries hot combustion products into the upper layer. As the compartment fills with these hot combustion products the upper layer descends. We have constrained the fire in CFAST to be constrained by the oxygen concentration. Thus, when insufficient oxygen in the room has been used up the fire will stop.

Most of our tests are run with the mattress and boxspring in Compartment 1 being set on fire at the beginning of the simulation. The other furniture in the apartment is set at an ignition heat flux of 20 kW/m^2, which is a typical heat flux ignition for common household furnishings.

Figure 1: Layout of Apartment



For our project, we designed an apartment with two bedrooms (Compartments 1 & 2), a hallway (Compartment 3) and a living room (Compartment 4). The overall apartment has a width of 9.6 meters, a depth of 5.31 meters, and a height of 2.44 meters. Compartments 1 & 2 have a width of 3 meters and a depth of 4.25 meters. Compartment 3 has a width of 6 meters and a depth of 1.06 meters and Compartment 4 has a width of 3.6 meters and a depth of 5.31 meters. The ceiling and walls of the apartment are made with gypsum board (5/8 inch). There is a door to each bedroom and a front door. These doors are all have a width of 1 meter and a height of 2 meters. There are five windows in the apartment. Four of the five windows are situated 0.75 meters from the floor and are (0.75 m x 1 m). The last window is a larger window in Compartment 3. It is only 0.5 meters off the floor and is (1.5 m x 3 m). The furnishings in each room are described below.

Figure 2: Furnishings by Compartment

Compartment 1	Compartment 2	Compartment 3	Compartment 4
Mattress and Boxspring	Bunkbed		Sofa
Wardrobe	Wardrobe		Upholstered Chair
3-Panel Workstation	TV Set		TV Set
			Curtains

*Compartment 3 is a hallway, so we did not put any furnishing in it.

The goal of our project is to look at several different parameters that effect the growth of a fire in an apartment. The size of the room, number and size of vents, number and placement of furnishings, number of ignition sources, number and placement of sprinklers, and opening fraction of vents. We will study the effect of changing the size of the room, changing the opening of the vents, and using sprinklers.

The Effects of Vents

The opening of vents controls the supply of oxygen to the fire in the Compartment. If all the vents are all closed the fire can only burn as long as there is oxygen present. An opening fraction of 0 means that all vents are closed. An opening fraction of 0.5 means the vents are half open and an opening fraction of 1 means the vents are fully open.

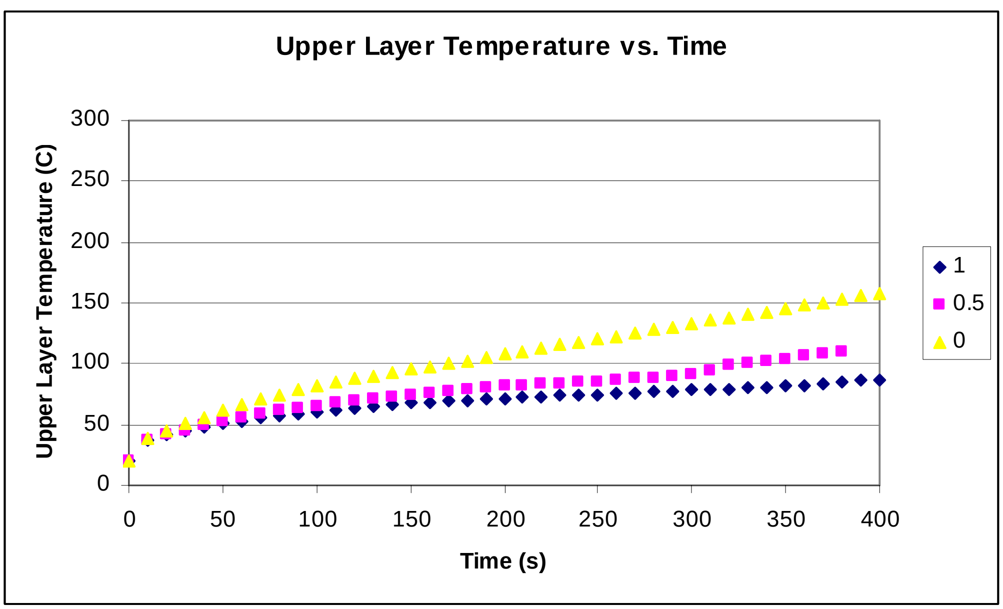


Figure 1: Effects of the vents on the Upper Layer temperature with 1 ignition source

In this scenario, a mattress and box spring is set on fire at the beginning of the experiment. As one would expect, the upper layer temperature is hotter when the vents are closed. When they are open it allows some heat to get out of the room and then enables the temperature to be lower. We still wanted to understand more accurately how vents were affecting the fire so we decided to set two ignition sources at the beginning of the simulation.

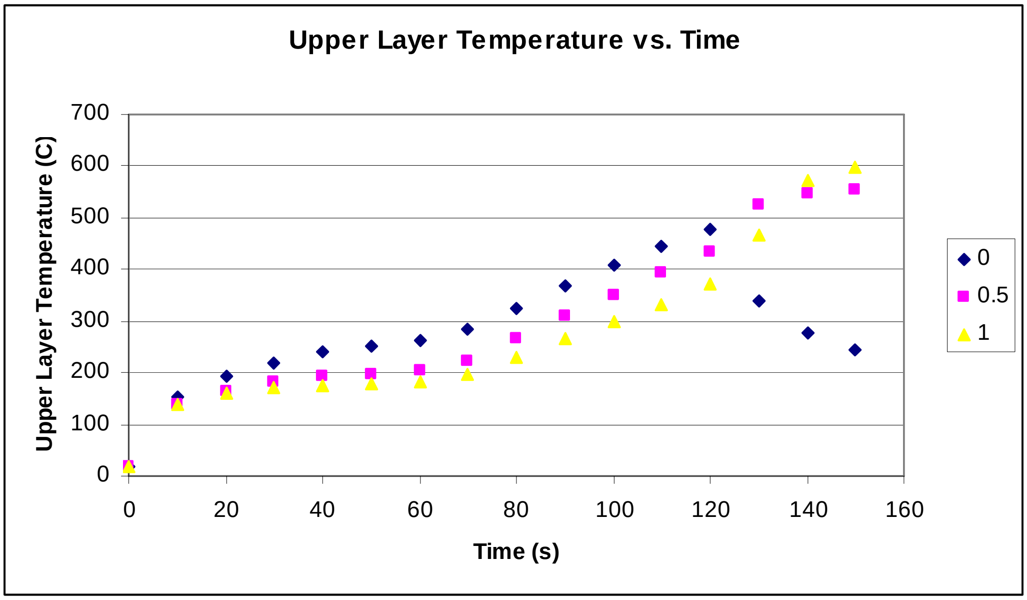


Figure 2: Effects of the vents on the Upper Layer temperature with 2 ignition sources.

In the second scenario we lit a mattress and box spring and a wardrobe simultaneously on fire and the graphs changed dramatically. As you can see, the trend of the upper layer temperature with time is similar in the beginning whether vents are opened, fully or not. It can be noted however that, as expected, the temperature when vents are closed is higher (more than 100°C) since there is no loss in heat flux with the outside because of open windows or doors.
Nevertheless, when we reach approximately 120 second we can see that the upper layer temperature will sharply decrease when no vents are opened. This is due to the fact that the fire now lacks the necessary oxygen to continue its growth. Therefore it starts to decrease and the temperature tends to decrease as well.

The upper layer temperature with the vents fully opened will increase to a value much higher than the situation with all closed vents due to the fact that the fire is allowed to continue to develop. It will also be higher than when the vents are just partially opened. This can be explained because the fire is growing rapidly since the room contains many fuel packets and there is a sufficient amount of oxygen to burn them.

At approximately 140 seconds the half open vent curve and the full open vent curve cross. This is interesting and could mean that at this point the fire is so big that quantitatively the amount of air coming in from the half open vent curve is not large enough to continue the evolution of the fire. Thus, in the end it clearly shows that the reaction is oxygen-dominated because the temperature will continue to increase with the size of the fire only if it has the sufficient amount of air (O_2) to continue burning the fuel packets that are in the room.

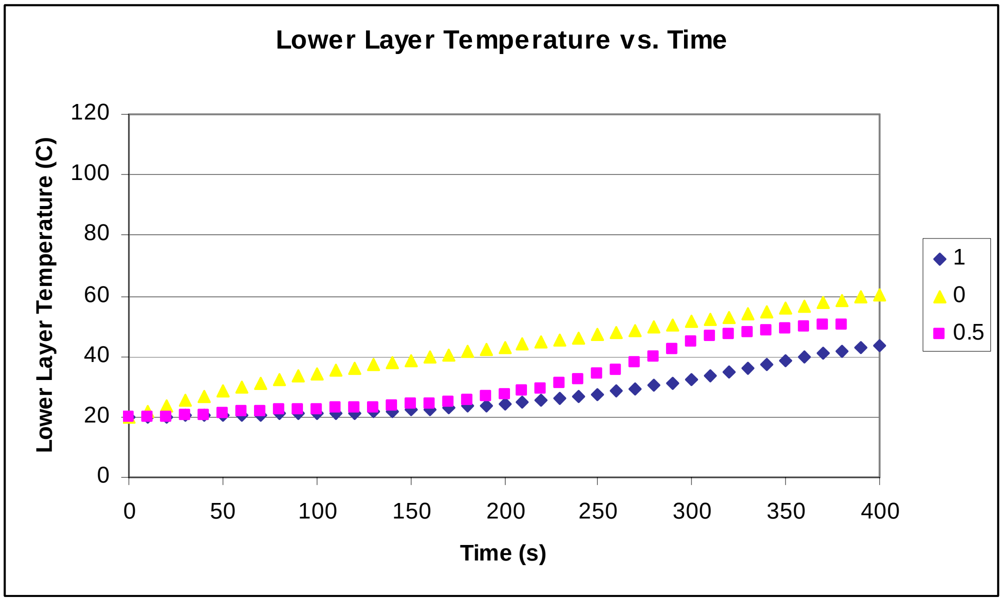


Figure 3: Effects of the vents on the Lower Layer temperature with 1 ignition source.

The lower layer temperature versus time graph is similar to the upper layer temperature versus time graph for one ignition source. The temperature is greatest for vents fully closed and lowest for vents fully opened.

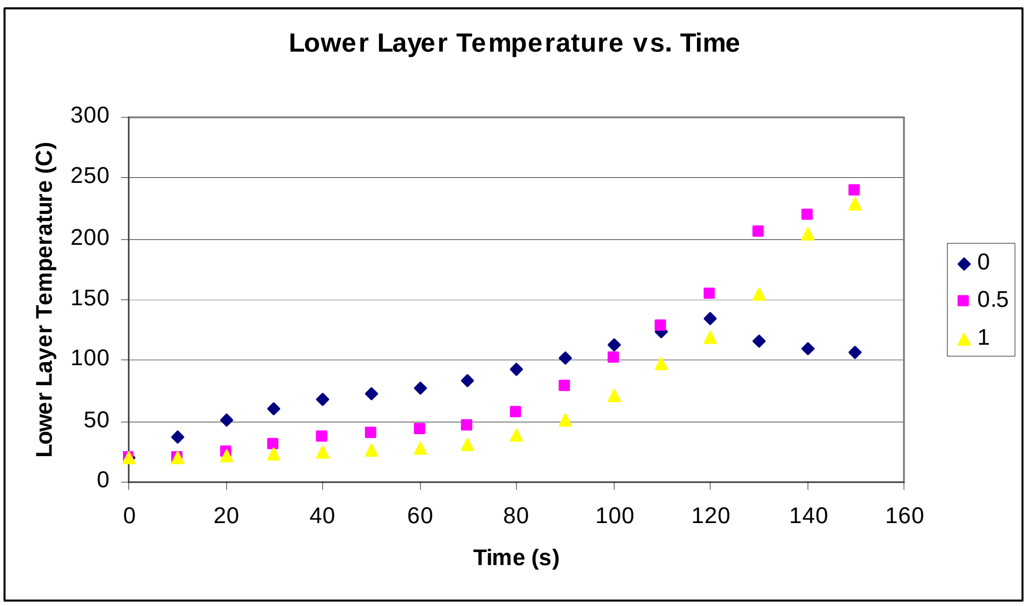


Figure 4: Effects of the vents on the Lower Layer temperature with 2 ignition sources

We also looked at the lower layer temperature versus time graph for two ignition sources set simultaneously. The scenario with all the vents closed initially has a greater lower layer temperature, but eventually decreases due to the lack of oxygen. The lower layer temperatures continually increase for the scenarios with the vents half and fully open.

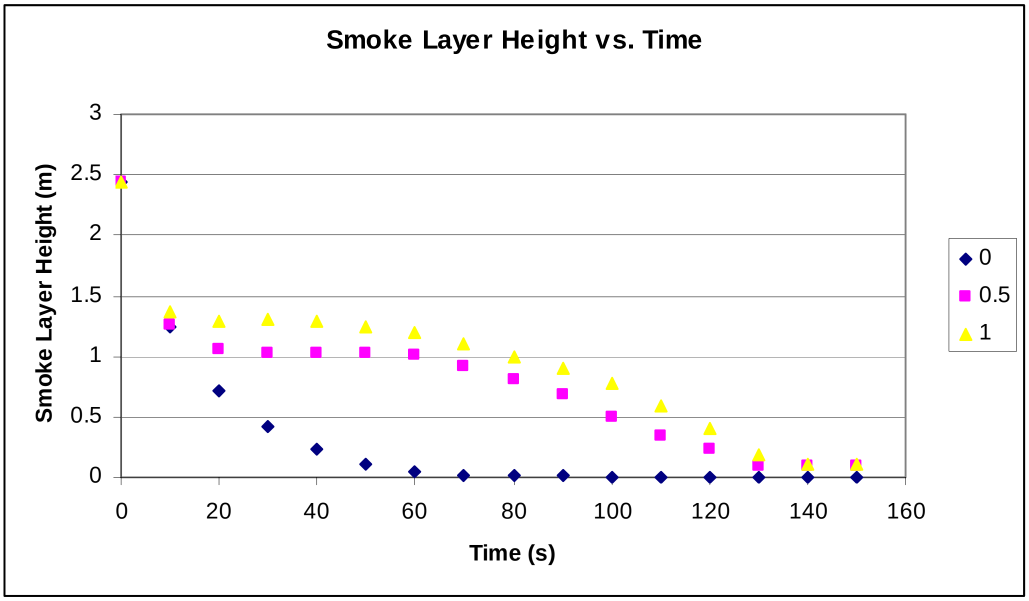


Figure 5: Effects of the vents on the Smoke Layer with 2 ignition sources

We also looked at the smoke layer height versus time for two ignition sources. We can see that when the vents are totally closed, the smoke will very quickly fill the room (around 50 seconds). Opening vents delays the filling of the room with smoke until approximately 130 seconds after the beginning of the fire. However, opening the vents halfway or opening the vents fully do not seem to have much effect on the trend of the smoke layer height curve.

Thus, having the windows open would give the occupants in the room more time to evacuate the room before it is filled with smoke and would therefore enable them to also stay conscious a little longer. However we can see that the temperature both on the upper-layer and the lower-layer increase as the vents are being opened more and more. Thus, occupants would experience greater temperatures which could cause third-degree burns or even death. The increase in temperature could also cause the fire to grow by igniting other fuel packets which could cause increased damage to the structure of the building. We will investigate these factors more deeply later on when we assess what happens when you “break” a window when the fire has been running for 5 minutes with closed vents.

The Effects of Sprinklers

Sprinklers are an effective way to control the size and spread of many fires. We will look at how using zero, one or two sprinklers effects the temperature in the upper and lower layers and the smoke height layer. The sprinkler is situated in the center of Compartment 1 for the case of one sprinkler (w = 1.5 m. d = 2.12 m). For the case of two sprinklers they are situated in the center of Compartment 1 approximately 1.4 meters apart in the depth direction (w = 1.5 m., d = 1.4 m and 2.8 m.). The sprinklers activate at a temperature of 73 °C.

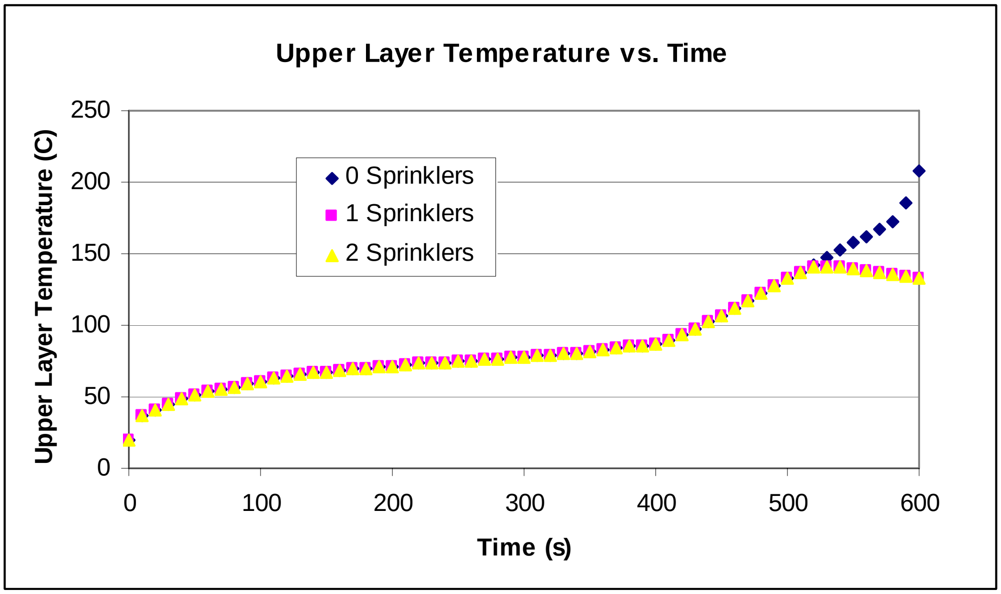


Figure 6: Effects of the Sprinklers on the Upper Layer temperature

One would expect to see a change in the upper layer temperature after it reaches 73 °C because this is when the sprinklers activate. However, the temperature of the upper layer is the same for each case until approximately 500 seconds. At this point the upper layer temperature decreases slightly for the case of one and two sprinklers, while still increasing rapidly for the case of zero sprinklers. Therefore, although the sprinklers activate at 73°C, they do not decrease the upper layer temperature until a great deal later.

One would also expect that by having two sprinklers we are going to accentuate the trend of one sprinkler. But in practice when we added the second sprinkler no significant change was noticed in the upper layer temperature. The two curves are in fact identical. After completing the test we realized that the CFAST model does not support the effect of a second sprinkler in a compartment.

All the other results (Smoke Layer Height, Fire size, Lower layer temperature..) follow the same trend so we are not going to present them here since the analysis would lead to the exact same conclusions.

Effect of Changing Ceiling Height and Vents Height

Another important parameter effecting fire growth is the size of the compartment that the fire is in. To highlight this, we will look at how the change in height of Compartment 1 affects the layer height versus time.

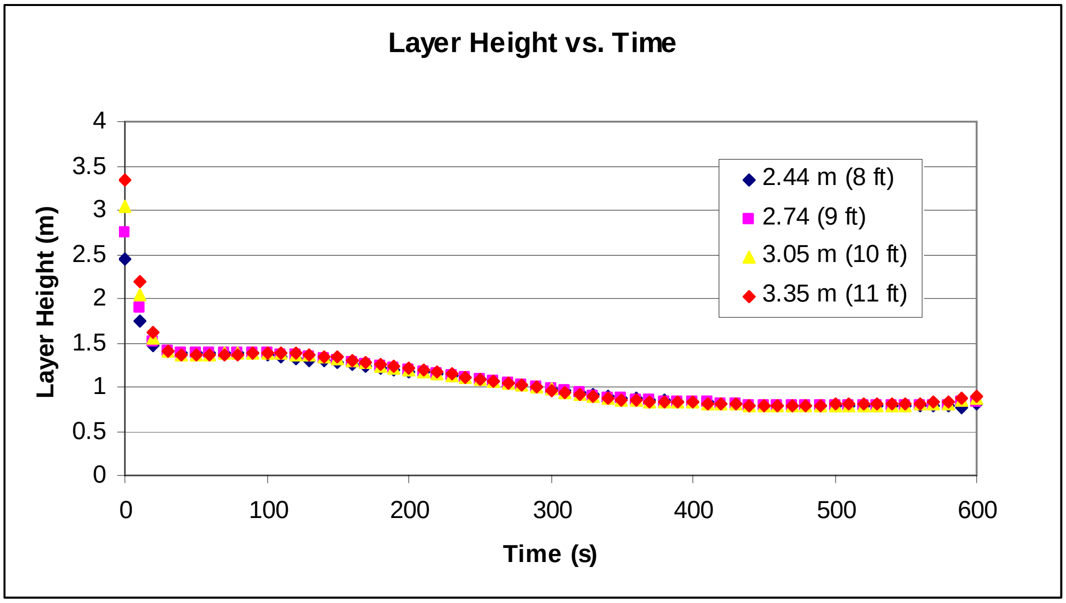


Figure 7: Effects of the height of the ceiling on the smoke layer height.

Obviously at the beginning of the experiment, the fire is just starting so the first data point for the layer height will be the ceiling height. However, after only thirty seconds the layer height becomes uniform at a value of approximately 1.4 meters for all four different ceiling heights. The layer height descends for all four different ceiling heights at the same rate until the layer height stabilizes at approximately 0.75 meters. Figure 7 shows that the ceiling height has little effect on the smoke layer height except at the very beginning of the experiment. Thus, the smoke layer height must be influenced by some other parameter. Therefore, we ran the following series of test, where we kept all parameters constant except for the height of the vents.

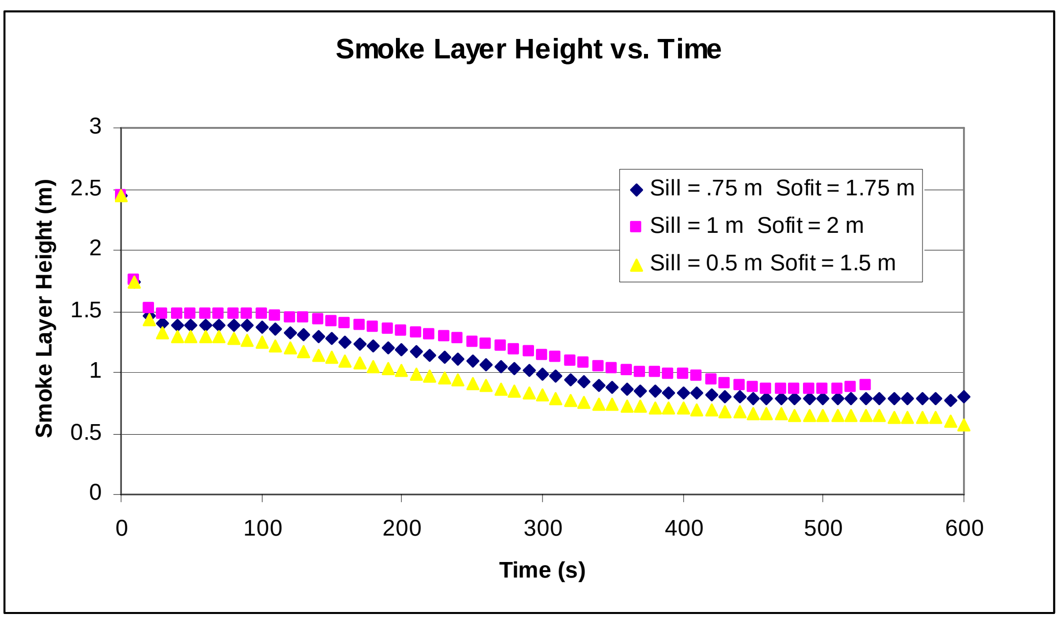


Figure 8: Effects of the height of the vents on the smoke layer height.

As you can see on the graph, the height of the vents (windows) clearly affects the smoke layer height. We kept the size of the windows the same and just moved them up or down and you can see that the layer height actually follows this movement. However it is more complicated that just moving up of the exact same value. For a 0.5 meter translation up, the smoke layer height increases approximately 0.3 meters.

Therefore, the reason the smoke layer height became uniform in Figure 5 after only 30 seconds was due to the fact that, although we changed the height of the ceiling, we did not change the height of the vents (windows). The height of the vents clearly controls the smoke layer height more than the height of the ceiling.

Fire Department Scenario: Window broken after 5 minutes.

We wanted to determine the consequences of breaking windows after the fire had started. This scenario simulates the action of a fire-fighter arriving at a fire scene. We assumed that the average response time of the fire department was approximately 4 minutes and that most smoke detectors would activate in about a minute. Therefore, we opened the windows in Compartment 1 after 5 minutes and analyzed the effects of this action on parameters such as the CO concentration and the fire size.

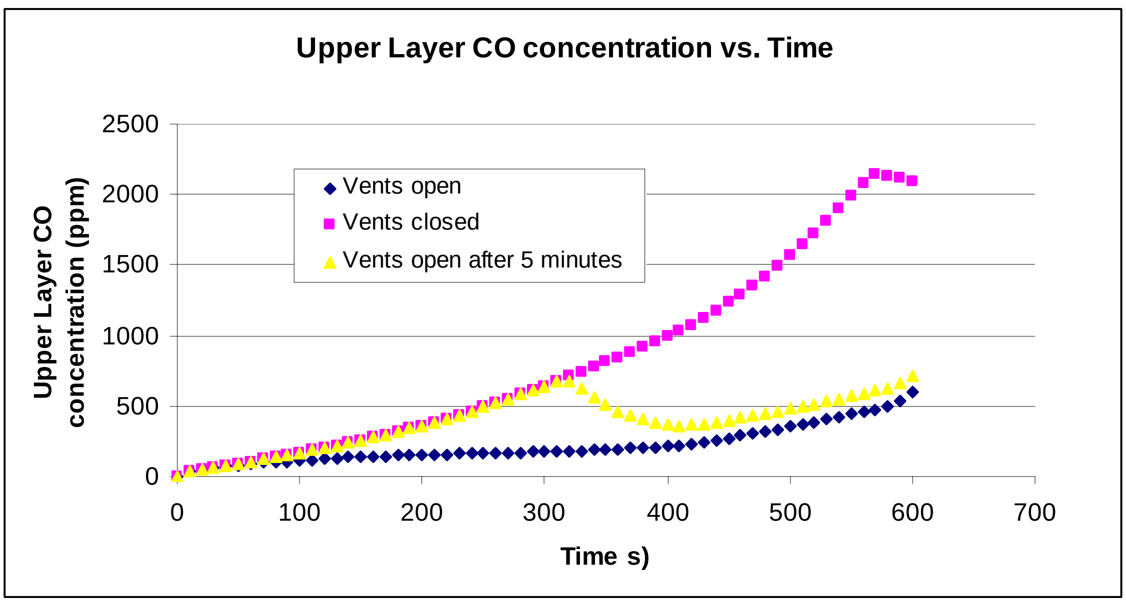


Figure 9: The effect of opening a window on the CO concentration.

The result of this experiment is significant. If we open a window at a time of five minutes, it drastically changes the trend of the CO concentration in the room until it approximately matches the CO concentration of the room with the windows always open. Even in the case of the windows always being closed we do not approach lethal doses of carbon monoxide which are 30,000 PPM over ten minutes. However we show here that by opening the windows in a room where there is a fire we greatly reduce the concentration of CO in the room. For a bigger fire, in a different configuration, opening a window could mean saving people's life by evacuating the CO before people in the room breathe lethal doses of the gas.

We also looked at the effects of breaking a window after five minutes on the smoke layer height. Indeed smoke is the cause of approximately 60% of the casualties related to a fire. So if we could reduce the time that people are exposed to smoke we would once again be able to save lives.

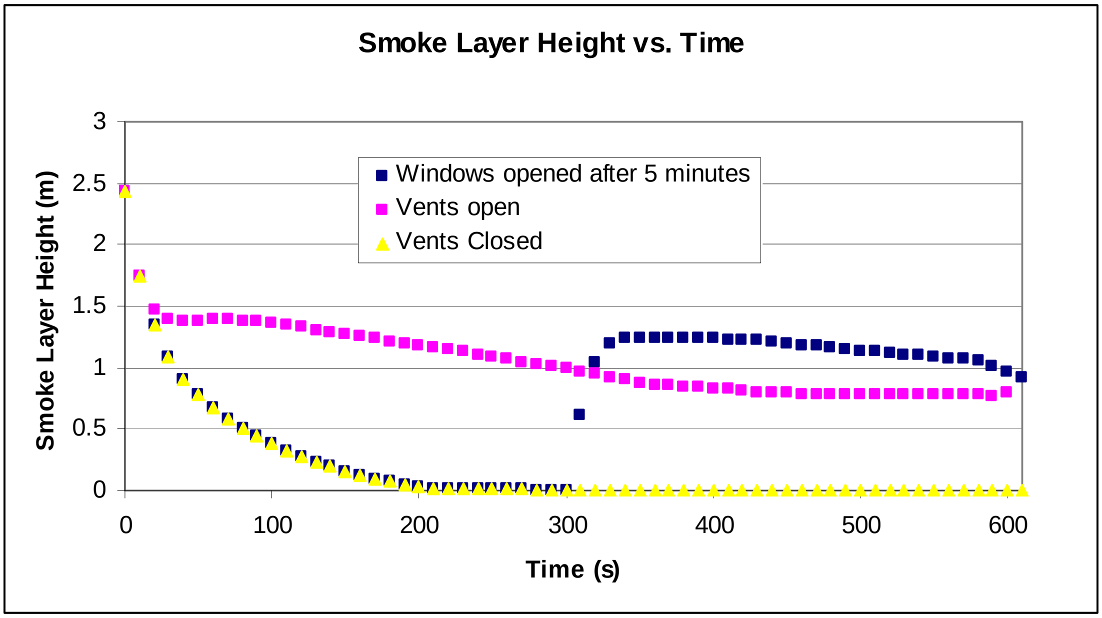


Figure 10: The effect of opening a window on the smoke layer height.

On this graph we can clearly see that by breaking the window we are evacuating the smoke out of the room and thus the height of the smoke layer rises. This is another element that shows that breaking the window is a good move after five minutes and can reduce the amount of time that people are exposed to harmful smoke. It really gives an excellent result since the layer height will even become higher than in the situation where the vents were open since the beginning!

Finally we wanted to check if opening a window had consequences on the size of the fire itself. With this test we wanted to analyse the potential effects on the infrastructure itself rather than just thinking about the occupants of the room.

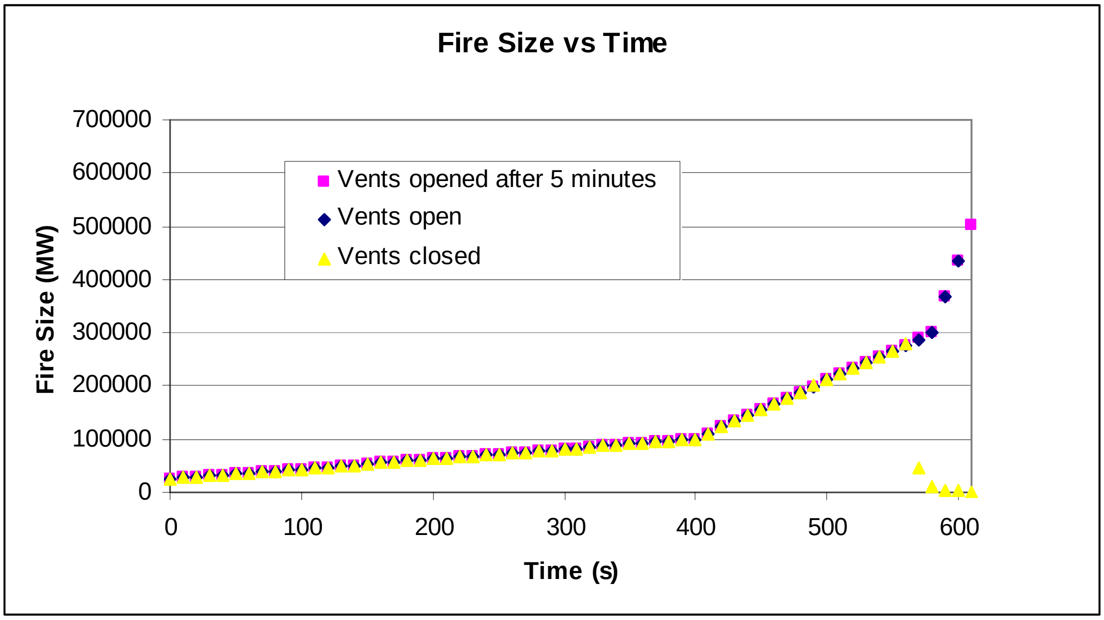


Figure 11: The effect of opening a window on the fire size

As you can see in the case where the vents are closed, the fire will finally reach a point where there is insufficient oxygen for it to continue burning, and it will just die by itself. The problem when opening a window at that time is that you will supply oxygen to the fire and it will then be able to burn all the remaining fuel in the room since it will be fuel-dominated and probably breach to another compartment if there is enough fuel for it to get powerful enough. You can clearly see on the graph that the fire has been supplied in oxygen when the window has been "broken" and that it will now match the trend of the chart corresponding to the always open scenario. So by breaking the window after five minutes, one actually stimulates the growth of the fire. Thus, the drawback of opening a window after five minutes is the input of oxygen and ultimately growth of the fire. Hopefully, the fire department is able to use the strategy of opening windows to save lives while at the same time using water to douse the fire growth.

Conclusion

We have investigated the effects of changing the height of the ceiling, changing the opening of the vents, and adding sprinklers. Lastly, we investigated opening a vent after five minutes. Our results show that changing the height of the ceiling of a compartment with vents has little effect on the smoke layer height. The smoke layer height is strongly dependent on the vent height. Our results also show that having vents open will induce lower values for both the upper layer and the lower layer temperature. However with closed vents, the temperature will suddenly decrease at some point because the fire itself will decrease due to a lack of oxygen. Our analysis on the effect of having sprinklers in a room led us to realize that sprinklers greatly reduce the temperatures in the room and increase the layer height. However, we were not able to model the effect of having more than one sprinkler in a room due to limitations in CFAST. Lastly, by opening the vents later during the experiment we were able to increase the smoke layer height and the decrease the CO concentration in the room, which enables people to survive longer in the room. However, the drawback was that it enabled the fire to grow more rapidly at the end due to an increase in the supply of oxygen.

Our scenario of opening the vents in Compartment 1 after five minutes illustrates the arrival of fire-fighters getting to the apartment and breaking a window when they get there. We found out that this was a good move if they were on the scene soon enough because they had a chance to save people by reducing the concentration of CO and the smoke layer height. However if the fire-fighters arrived at the scene too late, opening a window would just revive the fire and encourage it to grow more rapidly. This illustrates, at a much lower level of course, the kind of tough choices that the fire fighters have to deal with everyday.