

IMPROVING THE UNDERSTANDING OF POST-FLASHOVER FIRE BEHAVIOR

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ABSTRACT

Fire investigators are regularly called upon to interpret burn patterns and to determine where fires originate. Patterns created by pre-flashover fires are often easily deciphered by investigators seeking the fire origins. The severe burn damage found in fully-involved fires can be far more daunting to interpret, making origin determination extremely difficult.

At a 2005 fire training conference, fire investigators from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) designed and presented a seminar on Fire Dynamics. Two, identical, one-room burn cells with standard-sized doorways were each burned for seven minutes. Hours later, fifty-three fire investigator-students (who had not observed the fires) were asked to briefly examine the cells and decide in which quadrant of each cell they thought the fires had started. 5.7% of the students correctly identified the quadrant of origin in each cell. A review was undertaken of investigators' responses in similar, post-flashover exercises at the Federal Law Enforcement Training Center in Georgia. Though written records of those responses are not kept, anecdotal reports by long-time instructors indicate that since the class' inception in the early-1990s, about 8-10% of students correctly identified the fire's origin. Those who identified an incorrect origin typically reported they were misled during their analyses by extensive, post-flashover-generated burn patterns.

This paper offers a new and proven approach for enhancing investigators' understanding of post-flashover fire behavior through use of standard fire dynamics instruction combined with the graphic output of the computer programs, Fire Dynamics Simulator and Smokeview. Such training offers students a visual introduction to the nuances of ventilation-limited burning. It also introduces the use of computer models in hypothesis-testing as part of an investigative methodology.

BACKGROUND

The year was 2005. The location was a fire department training ground where two, new and nearly identical, single-room burn-cells had been constructed. Each cell measured 12-feet wide, 14-feet long and 8-feet high. Both cells were fitted with equal-sized, open doorways in the same relative positions. Each had been constructed by professional builders and was furnished with identical contents. The ceilings and walls were lined with one-half inch thick gypsum board attached to a wooden framework, finished and sealed. The roofs and floors were constructed of plywood sheeting attached to wooden studs. Each cell was fitted with thermocouple trees in the center of the room and doorway to record gas temperatures.

This was the scene of a burn exercise conducted by Certified Fire Investigators and a Fire Protection Engineer of the U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) that kicked off a training seminar for public- and private-sector fire investigators. Prior to students arriving on scene, the cells were arranged, photographed, and similar fires were set in a different location in each. Since a major focus of the class was on Fire Dynamics, it was the intent of the instructors to show the effects of ventilation on the different origins once flashover ensued.

The student population consisted of fifty-three fire investigator-students with a variety of backgrounds and investigation experience. The initial exercise called for a brief examination of

each fire scene. Students were directed to enter each burn cell and without removing debris, examine the resulting damage and estimate *in which quadrant* of the cell they believed the fire originated. They were advised that each fire was ignited in the same way but in different locations. They were also advised that each fire burned about 210 seconds until upper layer temperatures reached 600° C (a commonly accepted definition for the onset of flashover), and then another 120 seconds until extinguished. Students then submitted their written responses identifying the cells' quadrants of origin. For each cell, three out of fifty three students (5.7%) correctly identified the quadrant of fire origin. It was a different three in each case.

Later, the above results were discussed with long-time instructors and training managers for ATF's *Advanced Fire Origin and Cause* class. The semi-annual, two-week class has been held at the Federal Law Enforcement Training Center in Brunswick, Georgia since the early 1990s. It is designed to train experienced public sector fire investigators in advanced principles of fire science and fire investigation. Since the inception of the training, at the start of each new class, students enter and conduct a cursory examination of what is termed a "complex fire scene". As with the burn cell fire exercise in 2005, this scene evaluation is designed to gauge students' familiarity with ventilation-controlled burning. The scene includes a bedroom, living room/kitchen area, and a hallway connecting the two. Students are tasked with identifying the location of the fire's origin and briefly explaining their justification on paper.

Written records of students' responses to the complex-burn-scene exercise are not kept. Even so, according to anecdotal evidence from several sources, since the inception of the program, the percentage of students who correctly identified the area of origin has consistently been less than 10% of each class. Severe fire damage that occurred well after ignition and in a completely different part of the building was often misinterpreted as the site of fire origin.

These are just a few examples of similar training scenarios conducted by ATF in recent years that have repeatedly shown that a large percentage of even the most experienced fire investigators have difficulty interpreting the effects of post-flashover fire behavior. Participants were limited to a brief, visual, pattern examination and not given a chance to gather additional information for a more thorough review. Nonetheless, the exercises did reveal that far too often, investigators confused "lowest burn, deepest char" type patterns as indicative of fire origin. What investigators say most baffled them was the damage from the fully-involved, ventilation-controlled burning.

One difference in pre- and post-flashover fire behavior that many investigators are unaware of is that after flashover, the dominant factor controlling burn pattern generation is oxygen availability. After the onset of flashover, oxygen concentrations throughout much of a compartment fall to near 0%.^[1] Investigators must be able to visualize how oxygen-rich air enters a compartment and where it moves once inside. Incoming air is, after all, not static. It has momentum. This momentum causes the air to flow somewhat like the flow of water in a stream. Common sense principles apply to the flow. For example, it does not make sharp, 90° turns, nor does it immediately reverse directions. It simply moves so as to equalize pressure differences caused by the rising, buoyant gases. Even with chaotic conditions after flashover, air movement, though turbulent, still adheres to usual trends.

For investigators to accurately interpret post-flashover, ventilation-controlled fire damage, they need to imagine the fire's history and how and where fuel and oxygen would have interacted. A virtual video-playback of the fire should run through their minds emphasizing air flow and localized heat flux intensities. Full appreciation of burn patterns is difficult without an ability to visualize how such damage came to exist and why. Unfortunately, most investigation training does not yet emphasize this aspect of fire sleuthing.

Practical evaluations like those mentioned above reveal a lack of appreciation for the differences between pre- and post-flashover burning. A success rate of less than 10% of investigators accurately determining the origin of one- or two-room fires even after short periods of post-flashover exposure is of concern. Since the concepts of ventilation-controlled, post-flashover burning are well understood in the fire science community, it falls upon fire investigation trainers to provide that knowledge to the practicing investigator.

REVIEW OF EXISTING INVESTIGATIVE REFERENCES

Since the early 1990s, instruction in the general concepts of fire behavior up to and including flashover has greatly improved. As an example, the causes of floor-level, burn pattern generation during flashover conditions have received considerable attention. This has led to the now widely-accepted view that many floor patterns (that would have previously been attributed to burning ignitable liquids) are actually due to upper-layer radiation. The increased awareness of just this one aspect of fire science has greatly benefited the profession. Still, more needs to be done to educate investigators about the ensuing fire behaviors.

Notably lacking in much of the current training is a comprehensive emphasis on the ideas of fuel-controlled and ventilation-controlled burning. These topics are discussed in popular investigation-related resources such as *NFPA 921, A Guide to Fire and Explosion Investigation*^[2], *Kirk's Fire Investigation*^[3], and the *User's Manual for NFPA 921*^[4], but the details correlating these ideas with burn pattern development are only briefly mentioned. DeHaan and Icové offer some of the most complete explanations of how ventilation-controlled burning (again as related to the post-flashover stage) affects fire damage. DeHaan states, "In a post-flashover fire, the locations of the most energetic combustion (and accompanying thermal effects) are no longer controlled by where the fuel packages are, but by where the best ventilation is located."^[5] He and Icové also explain that, "In preflashover rooms, the most intense thermal damage will be in areas immediately around (or above) fuel packages. In postflashover fires, all fuels are involved and the most efficient (highest temperature) combustion will be occurring in turbulent mixing around the ventilation openings."^[6] While this is correct, the need for more extensive discussions remains. Even basic training classes ought to stress the principles governing fuel- and ventilation-controlled fires.

In addressing this concern, the author fashioned a new training program designed to emphasize basic fire science and the need for investigators to visualize air flow and the related burning in post-flashover, fully-involved fires. The program starts with an overview of fire dynamics including simple fire chemistry, combustion theory, thermodynamics/heat transfer, and fundamental fluid mechanics as related to fire. Differences with many current classes lie not in the basic science offered, but in the focus of presentation. As mentioned, investigators need a comprehensive understanding of how and why heat fluxes in fully-involved fires can reach upwards of 150 kW/m^2 ^[1] and temperatures can be as high as $1,200^\circ \text{ C}$ ^[7]. Such knowledge is vital since many building fires often become ventilation-controlled once they achieve flashover. Post-flashover burn patterns are generated more quickly than in pre-flashover fires since it is in this state that fires generally burn with maximum ferocity. Not only can the damage be extensive, it can also easily occur far distant from the fires' origins. Simplified discussions of the physics and chemistry behind such behavior are included.

HISTORICAL SCIENTIFIC RESEARCH

Ventilation-controlled fires have been studied for many years. Kawagoe,^[8] one of the early researchers of fully-developed fire conditions, first introduced the concept of a ventilation factor that affects a fire's growth. This factor is related to and dependant on the size of

ventilation openings. Later studies by Thomas and Heselden ^[9,10] and Harmathy ^[11,12] expounded on the concept of a ventilation factor and led to a conclusion that in compartment fires, there are two regimes of burning behavior, fuel-controlled and ventilation-controlled. By definition these suggest that a fire's burning rate is determined by either (1) the fuel surface area available to participate in the combustion reaction or (2) the amount of oxygen available for combustion. Walton and Thomas ^[13] explain that, "... in the case of fire in the open, it is the local fuel concentration that controls the reaction ... In ventilation-controlled enclosure fires, the air is deficient and it is then the oxygen concentration that controls the reaction."

For ventilation-controlled compartment fires, Harmathy suggested that while a fire's burning rate depends on the ventilation factor, it also depends on both the size and shape of a compartment. Later, Kumar et al. ^[14] conducted experiments related to the effects of cross ventilation on both gas temperatures and mass loss rates. As one might intuitively expect, their work showed that with cross ventilation, compartment fire gas temperatures were higher than for fires with only a single vent.

Thomas and Bennets ^[15] examined fires in long and wide enclosures. In those, they observed that flames burned somewhat erratically over a series of liquid fuel trays. After becoming ventilation-controlled, flames occurred at the front of the fuel tray closest to the vent. Once the fuel in that tray burned away, the flames then moved away from the vent towards the next tray closer to the rear of the compartment. Burning was clearly controlled by the availability of air since fuel was plentiful. Utiskul ^[16] reported similar observations in ventilation-controlled fires, where flames only existed in regions of sufficient oxygen despite an overabundance of fuel gases throughout the compartment. At times, with vitiated (oxygen deficient) air, flames did not even cover all of the exposed fuel area. Hu et al. ^[17] described a similar phenomenon when, in a ventilation-controlled fire, flames migrated away from the original fuel location and stabilized nearer the compartment vents.

While such occurrences seem to be a straightforward extension of the lesson of the fire triangle, this type of behavior seems underappreciated by fire investigators. Many consider flame locations synonymous with fuel positions. While true during pre-flashover conditions, after flashover in most compartments, fuel gases essentially fill the compartment but burn only where they encounter sufficient oxygen. Under such conditions, a fire is ventilation-controlled; there is insufficient oxygen entering the compartment to burn all the fuel gases inside. Instead, unburned fuel gases flow out of the compartment and burn only after they encounter sufficient oxygen.

In a post-flashover compartment fire with an open vent, hydrostatic pressure differences cause hot combustion gases to rise into the upper layer and flow out of the compartment through the top of the opening. The resulting lower pressure draws cooler, oxygen-rich air in at the bottom of the vent. A "neutral plane" exists in between the layers where there is virtually no gas movement in or out of the compartment. Quintiere ^[18] reported that in post-flashover burning, shear mixing" can occur inside the compartment near the neutral plane thus reducing the oxygen concentration in the lower layer.

Utiskul, Hu et al., and Williams ^[19] offer various theories of how such mixing reduces a fire's burning rate. Based on his studies of fully-developed, ventilation-controlled compartment fires, Utiskul theorized that decreases in mass loss rates due to insufficient oxygen can lead to flame extinction. In such fires, changes in a fuel's mass loss rate (and thus its burning rate) are often independent of the quantity of fuel available. They are instead dominated by compartment-related effects such as limited ventilation / oxygen depletion and radiant feedback to the fuel.

Hu et al. report the use of the computational fluid dynamics (CFD) computer model, Fire Dynamics Simulator (FDS), developed by the National Institute of Standards and Technology, to simulate conditions in a ventilation-controlled compartment fire. In general, they showed that the agreements between experimental and computational data related to the mass flow (movement of both hot and cool gases) as well as the oxygen concentrations were *very good to excellent*. While the model accurately described these factors, it was unable to discern more precise flame behaviors such as flame quenching observed in actual experiments.

Utiskul indicated that current models (including CFD models such as FDS) do not reduce a fuel's mass loss (and thus burning) rate because of increased vitiation nor do they enhance it due to radiation from the hot gases or compartment enclosures. In actual fires, these factors have a substantial affect on a fire's growth. Babrauskas reports, for instance, that the heat release rate of burning objects, such as mattresses, can be increased by a factor of 2 in a post-flashover room fire^[20]. As a result, without including these considerations while calculating burn rates, the models have difficulty predicting temperatures, heat release rates and fire duration during fully-involved, post-flashover conditions.

In the early 1980s, Steckler, Quintiere and Rinkinen^[21] studied and reported on fire-induced flow in compartments. Their principal focus was on the effect of ventilation streams early in a fire's development. They showed that such ventilation streams can cause a flame to lean over significantly. The greatest affect occurs to fires located just inside a doorway. The effect decreases as the fire moves back away from the vent. The resulting entrainment can be as much as three times that of a fire with a free-standing plume and can significantly increase its burning rate. This work demonstrated how a fuel's burning rate can vary solely because of its position in a compartment and the localized ventilation environment there.

Based on the above works, regardless of whether a fire is burning pre- or post-flashover, ventilation conditions can have a pronounced effect on its behavior. Investigators must learn to account for such effects when interpreting burn patterns. Severe burn damage can not be considered merely as direct evidence of the length of time a fire burned and where its fuel source was located. The errors made in origin determination at the FLETC and 2005 burn scene exercises largely resulted from the misinterpretation of post-flashover fire damage. With increased training emphasis on the roles of ventilation during both fuel-controlled and ventilation-controlled burning regimes, investigator performance can improve.

FIRE INVESTIGATION-RELATED RESEARCH

In about the past ten years, studies have begun to focus on the relationships between fully-involved fires and fire investigation. In December 1997, Putorti^[22] reported his findings on burn patterns generated in full scale room fires. A National Institute of Justice report arising out of his research stated that, "Significant differences in the condition and appearance of the burn rooms and furnishings were present between experiments with the same method of ignition. The differences consisted of the severity of burning, the location of the patterns, and the type of patterns present. Overall, there was a lack of pattern consistency. As mentioned previously, ventilation effects are the likely cause of the pattern inconsistencies, and should be tightly controlled in future experiments."

In 2007, Hopkins et al.^[23] issued a report specifically addressing the affects of both pre-and postflashover fire conditions on the creation and persistence of burn patterns. In their discussion, they mention that, "...almost identical heating or a similar magnitude of heat flux..." occurs to a compartment's boundary materials after a transition through flashover. The concern that some

fire investigators rely on such knowledge and, "... often regard the initial plume patterns as being destroyed or obscured", was a major impetus prompting their work.

They state that, "...almost identical heating or a similar magnitude of heat flux..." occurs to a compartment after flashover. Though this premise has a wide following, research has actually shown that in much of the post-flashover period, heat fluxes are quite variable depending on the location in a compartment. Perhaps the misconception that they are similar is derived from the thought that since the entire compartment is involved in fire, then heating must be near-uniform. In reality, once a fire becomes ventilation-controlled and fully-involved, active burning in a compartment is often far from uniform. The most energetic combustion (as described by Thomas and Bennets¹⁸ and Utiskul¹⁶) occurs where there is sufficient oxygen-rich air. The highest fluxes are then associated with the highest temperature flames. While such burning will likely occur in the regions adjacent to vent openings, it may also exist well into a compartment if the incoming air flow has sufficient momentum to travel far enough before being consumed. Elsewhere in the compartment, although the average flux will be higher than that typical of the pre-flashover stage, some radiation emitted from the most energetic areas of flaming will be absorbed by the intervening thick smoke before reaching the compartment boundaries.

The authors explain that pre-flashover patterns typically associated with fire plumes were generated early in their tests. They provided descriptions for fuel types and locations, listed the varying pre- and post-flashover burn-times, and discussed burn pattern development. Less detail was offered regarding ventilation conditions (e.g. extent of vent openings, if windows failed and when, etc.) that would have played a significant role in creating post-flashover burn patterns.

In their conclusions, the authors acknowledge there are, "...thousands of variables that can affect both fire growth and subsequent pattern formation...", and suggest that most are linked to ventilation. Yet without much discussion of the tests' ventilation conditions, they state, "These tests reaffirmed that fire patterns persist during post flashover conditions, as well as provide evidence of the evolution of these fire patterns. This research revealed that the initial plume patterns are not lost, in fact, the experiments presented here have shown that the demarcation lines or initial patterns formed by the plume persist after flashover." This claim, though applicable to the specific settings of these experiments, does not yet appear to fully extend to all fire conditions. To their credit, Hopkins et al. state that additional research is needed and that they have plans to conduct that research.

Much work remains to qualitatively and quantitatively compare burn pattern generation and masking in pre- and post-flashover fires. There remains a need for comprehensive studies of heat fluxes and fire damage generated under various post-flashover, compartment configurations before the investigation community can unilaterally embrace or reject the idea of widespread pattern persistence. While it may not have been the authors' intent to suggest that all or even most early plume-generated patterns will survive all post-flashover burning, readers lacking a thorough understanding of the specific circumstances of these experiments might erroneously reach such a conclusion.

RECENT TRAINING EFFORTS

Attempting a new approach to improve understanding of post-flashover, ventilation-controlled fires, the author employed FDS modeling and Smokeview to compute and display visualizations of the 2005 training seminar burn cell fires. In early 2006, efforts commenced to model these fires using FDS version 4.0. Aware of the limitations discussed by Utiskul¹⁶ of using any computer model to simulate actual fire growth, the decision was made to make a "best effort" attempt at specifying the type and locations of the fuels involved, and if the results seemed

reasonable, to focus attention on the model's strengths in calculating fluid flows. Such results would at least prove useful in demonstrating general trends in compartment fire behavior such as ventilation flows.

Calculations in the interior of the compartment domain (3.4 m x 4.0 m x 2.6 m) were made using a relatively fine mesh (5.0 cm x 6.25 cm x 6.5 cm). A coarser mesh (10 cm x 10 cm x 9.6 cm) was used in that part of the domain outside the compartment (1.0m x 4.0m x 2.6m) for determining exhaust/in-flow gas conditions. Interior walls and ceiling were assigned boundary properties for ½-inch-thick gypsum board and material properties for the furnishings were selected from the version 4 materials database.

The actual fires were ignited in crumpled sheets of newspaper. In the first burn cell, they were contained in a polyethylene basket measuring 0.15 m² in area. The two fires were defined in the model as having the same cross-sectional area and having a 90-second linearly-ramped growth rate to a peak heat release rate of 300 kW. FDS calculated the fuel mass loss rates using the default combustion model. The model was instructed to capture output data including oxygen and carbon monoxide concentrations, temperature, and gas velocity in various slice files. Boundary conditions were also recorded for gauge heat flux, burning rate and wall temperature.

The programs were run using a Windows-based, single-processor computer with a processing speed of approximately 2.8 GHz. Performing 420 seconds of burn-time calculations using FDS took approximately 100 hours of real-time processing. Using these parameters, the model estimated the onset of flashover (upper layer temperature of 600° C) at about 278 seconds. This was approximately one minute slower than was actually measured in the fires. Despite this time lag, considering that the model did not take radiant feedback in the fire's growth into account, the results were considered acceptable, particularly since the model appeared to treat air/smoke flows accurately. Smokeview was then used to generate "snapshots" and video sequences showing calculated gas concentrations and heat fluxes at various stages. These "snapshots" were later used in presentations to help students visualize the ventilation-controlled fire behavior.

In the first burn cell, the fire was ignited alongside the bed near the rear corner. After the fire, a nearby clean-burn pattern was visible on the wall between the bed and a chair located in the corner. Like some of the pre-flashover burn patterns Hopkins et al. discuss in their studies, this clean-burn survived subsequent post-flashover damage. As calculated by the FDS modeling of the first burn cell, the most energetic post-flashover activity and resulting burn damage occurred along the pathway that oxygen-rich air flowed from the open doorway to the wall directly across the room. That wall showed a wide-based area of clean burn extending to floor level. There was virtually no fresh air that flowed towards the origin in the rear corner behind the bed. Without such an oxygen supply, vigorous post-flashover burning and accompanying high heat fluxes never occurred there, leaving the pre-flashover burn patterns visible.

In the second burn cell, the fire was ignited along the front side of the bed, about three feet from the open doorway. As in the first cell, an area of clean burn and intense heat damage was apparent on the rear wall directly opposite the door. This was quite similar to the damage that occurred in the first cell. At the origin of this fire, no distinct patterns survived to enable any of the ATF CFIs or FPE to identify it even though they knew exactly where it had been ignited. In this instance, high post-flashover heat fluxes from energetic, ventilation-controlled burning fed by a plentiful supply of oxygen had thoroughly masked areas of early fire damage. Each of the investigators remarked that if they had not observed the fire's origin, they could not have identified it from burn patterns alone. Interestingly, the chair in the rear corner of the second burn cell survived the fire much better than had its counterpart in the first cell. Clearly, much of

the damage to the chair in the first cell had been caused prior to flashover since the post-flashover, ventilation-controlled damage in the rear corners in both fires were comparable.

The fact that both cells sustained similar damage to the rear wall directly opposite the open doorway is an indication that the damage was primarily due to post-flashover flames being enhanced by incoming, oxygen-rich ventilation flowing to that wall. It is postulated that if either fire's origin had been located at or directly opposite the open doorway, it would have likely been extremely difficult if not impossible to recognize by visual pattern-interpretation alone. In both cells, the damage to the rear-wall gypsum board (opposite the door) was severe and any calcination caused by a pre-flashover fire plume would have been masked when the overwhelming, post-flashover heat impingement that dehydrated most if not all of remaining water from the gypsum board. Accordingly, even methods such as 'depth of calcination' analyses' and heat vector diagrams would like have been unable to differentiate pre- from post-flashover damage.

Post-fire FDS analyses can be enhanced by examining heat fluxes (and other values) at various user-specified locations. Figures 1 through 5 show the calculated boundary layer heat fluxes of the first burn cell fire at specified times. Such visualizations from Smokeview can be examined in myriad ways as the user chooses. Figure 6 is an actual panorama of post-fire photos showing the area depicted in Figures 4 and 5. Note the similarities with the calculated areas of damage.



Fig. 1 - Wall heat flux 2.5 min before flashover
Max flux in upper right corner $\approx 90 \text{ kW/m}^2$

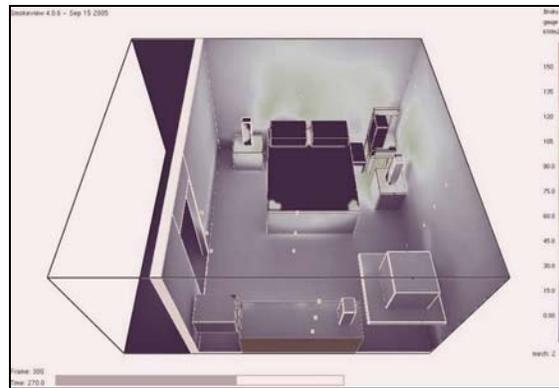


Fig. 2 - Wall heat flux 10 sec before flashover
Max flux at head of bed $\approx 60 \text{ kW/m}^2$

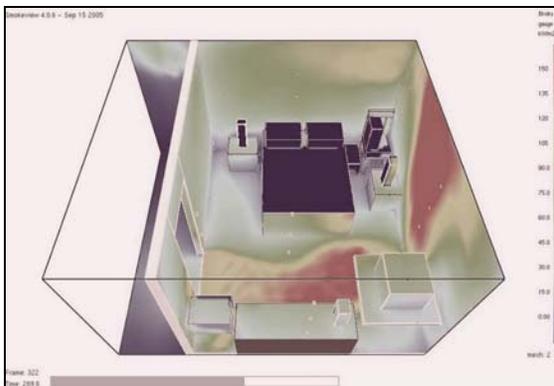


Fig. 3 - Wall heat flux 12 sec after flashover
Max flux at right wall $\approx 150 \text{ kW/m}^2$

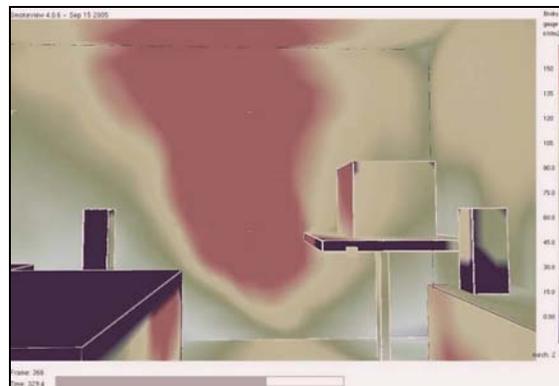


Fig. 4 - Heat flux opposite open doorway
10 sec post-flashover. Max flux $> 150 \text{ kW/m}^2$

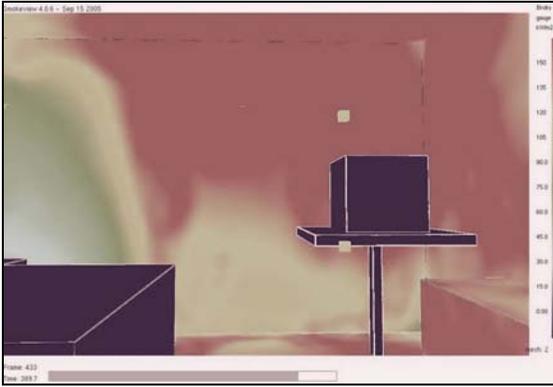


Fig. 5 - Heat flux opposite doorway 2 min post-flashover. Max flux > 150kW/m²



Fig. 6 - Photo panorama of wall opposite open doorway. Note similarities of clean-burn to areas of high heat fluxes shown in Figs. 4 & 5

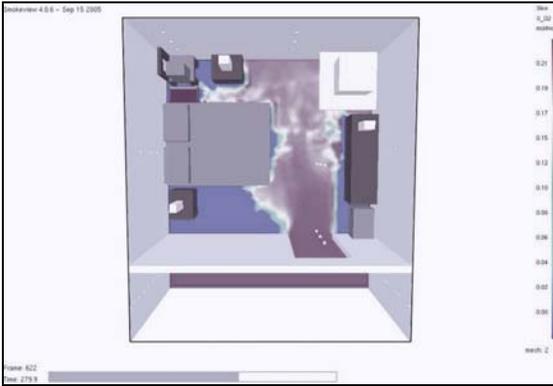


Fig. 7 - Percent oxygen. 0.2m above floor 2 seconds after flashover

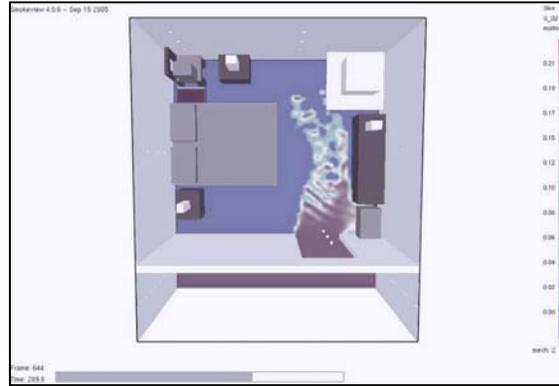


Fig. 8 - Percent oxygen 0.2m above floor 12 seconds after flashover



Fig. 9 - Percent oxygen in doorway 150 sec before flashover

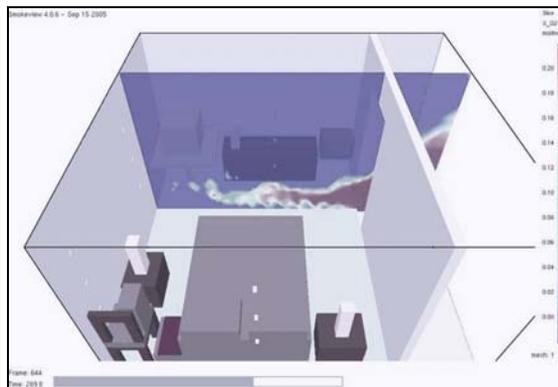


Fig. 10 - Percent oxygen in doorway 10 sec after flashover

The FDS calculated data supporting these “pictures” can also be graphically represented for a more mathematically-based review. The graph in Figure 11 shows the heat flux vs. time that FDS estimated at two locations. The darker curve represents the flux at the rear wall, 0.4 meters out from the adjacent wall (against which the head of the bed was placed). The second curve represents the flux at the rear wall 2 meters away and directly opposite the open doorway. Each reference point was 2 meters above the floor. (Because of slight instability in the original calculated data, each displayed curve represents a moving average of the data over 5 iterative cycles so as to minimize fluctuation). Since the curves represent heat flux as a function of time, in order to determine the total heat exposure at these points over a length of time ‘t’, the areas under each curve must be measured / determined from initial time, ‘t₀’ to time ‘t’. As the graph illustrates, the total heat impacting the point opposite the doorway is at least as great as that affecting the point closer to the origin. It should be remembered that since the actual fire burned 210 seconds in both the pre- and post-flashover stages (for a total of 420 seconds), the graph represents a lower overall heat impact than what actually occurred. That is because the graph is of the FDS calculated output which estimated that upper layer temperatures of 600° C did not occur until 68 seconds after they were actually measured in the fires.

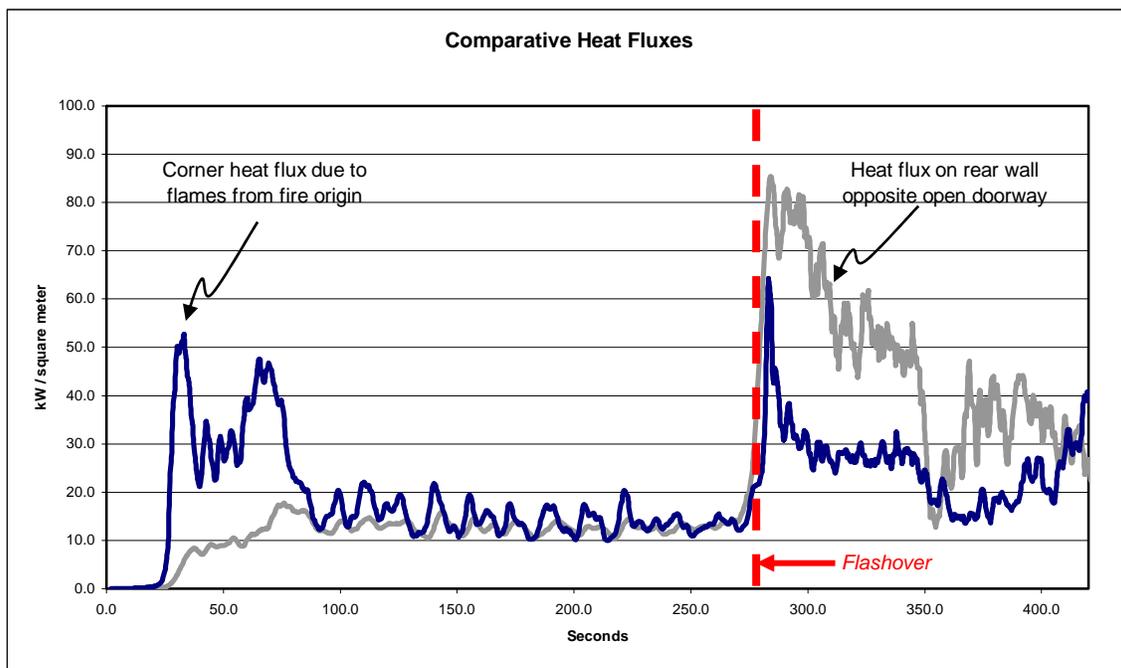


Fig. 11 -Graph of heat flux measured above fire origin and on rear wall across from doorway

Since 2006, this training system has been presented across the U.S. and in Canada at eight seminars for approximately 1,000 fire investigator-students. Feedback from hundreds of students who have attended the training has been overwhelmingly positive. Several have commented that for the first time, they felt like they gained a functional understanding of the importance of ventilation in post-flashover burning. Many felt confident that they could apply these newly-learned principles to form and test hypotheses during fire origin and cause determinations.

Additional efforts are planned to expand this technique to examine several more compartment/ventilation configurations. Among the variables that should be included in future analyses are the number, size and location of vents, types of vents, and times of opening/closing.

Further, in order to make such analyses of small fire domains (one- or two-room scenarios) practical for more investigators, sensitivity studies would be helpful to determine the appropriate mesh size to maximize the effectiveness while minimizing modeling times in single-processor or even dual-core processor computers. It is possible that even though fine detail may be lost in quicker tests using increased mesh sizes, the fundamental fluid flow behaviors will still be identifiable and sufficiently helpful to isolate various scenarios for a later, more intensive inspection.

By showing calculated ventilation flows for a wide range of compartment arrangements and using such techniques to test/challenge their abilities in estimating these flows, it will hopefully encourage and reinforce the students' use of visualization techniques during hypothesis generation and testing.

ABOUT THE AUTHOR

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