Ventilation Strategies: International Best Practice

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Introduction

The chemistry and physics of fire remains consistent throughout the world. However, there is considerable diversity in the strategies and tactics used by firefighters.

> From the remotest periods of antiquity to the present time, the business of extinguishing fires has attracted a certain amount of attention; but is a most curious fact that, even now, there is so little method in it in that it is a very rare circumstance to find any two countries, or even any to cities in one country, adopting the same means, or calling their appliances by the same name (Shaw, 1876)

For as long as humankind has known about fire, its control has been a topic of study. But for all we know about fire there is much more to learn. Ventilation is a key factor in both fire development and control and yet there continues to be considerable misunderstanding and misapplication of ventilation strategies and tactics. Vertical ventilation (see Figure 1), positive pressure ventilation, and anti-ventilation tactics are often embraced or rejected without any scientific evidence or operational experience.

Figure 1. Vertical Ventilation

Control of ventilation has been used as a firefighting strategy for many years, but has evolved along two paths. One approach is to exclude air to limit the oxygen required for combustion.

> The men of the fire brigade were taught to prevent, as much as possible, the access of air to the burning materials. What the open door of the ash-pit is to the furnace of a steam-boiler the open street door is to the house on fire. In both cases the door gives vital air to the flames (Braidwood, 1830)

> On the first discovery of fire, it is of the utmost consequence to shut, and keep shut all doors, windows, or other openings. It may often be observed, after a house has been on

> fire, that one floor is comparatively untouched, while those above and below are nearly burned out, this arrises from a door on that particular floor having been shut, and the draught directed elsewhere (Braidwood, 1866)

However, another approach is to remove hot and toxic smoke and fire gases from the building.

> One of the major reasons that fires get out of control is the lack of proper and adequate ventilation…If you want to move in on a smoky fire, you must ventilate or your will be driven out. Yes, you can and should use masks to hold difficult positions. But most jobs [fires] will be readily controlled by good, fast ventilation and a crew determined to move in (Fried, 1972)

While the examples used to illustrate the two basic ventilation strategies were drawn from the 19th and 20th centuries and are to some extent reflective of the times, these concepts remain just as valid today.

International Differences

As Shaw (1876) observed, it is rare for two fire departments, much less two nations to follow exactly the same firefighting practices. However, application of ventilation strategies and other firefighting practices has evolved quite differently in the United States in comparison to Europe and Australia[1].

The philosophical approach to ventilation strategies in the United States may best be represented by the common fire service maxim *vent early and often*. Ventilation to remove smoke from the building is often implemented ahead of or simultaneous with fire control efforts. Ventilation tactics involve both horizontal ventilation through existing building openings and vertical ventilation, often involving cutting roof openings. While firefighting texts and training programs do address the need for coordination, control, and timing, ventilation frequently results in increased fire intensity and in some cases precipitates extreme fire behavior. This is not to say that deliberate and substantial increases in ventilation cannot have a positive impact on life safety and fire control. When used correctly, this strategy is extremely effective. Fire control and ventilation strategies are closely related. Given the tendency to vent aggressively, firefighters in the United States generally use flow rates ranging from 375 lpm (100 gpm) to 1100 lpm (300 gpm) in offensive firefighting operations (tending towards the middle of this range).

In contrast, the philosophical approach to ventilation strategies in Europe and Australia is quite different. Increasing ventilation is approached much more cautiously and deliberately and limiting the air supply to the fire (rather than removing the smoke and increasing air supply) is equally likely. Ventilation tactics focus largely on horizontal ventilation. Ventilation operations are more closely controlled with a strong focus on integration of fire control and ventilation operations. Correspondingly, firefighters in Europe and Australia typically use flow rates ranging from 115 lpm (30 gpm) to 750 lpm (198 lpm), tending towards the lower end of this range.

[1] It is important to note that these philosophic approaches are extremely generalized and do not necessarily reflect the practices used by a given fire department.

Key Questions

To start this examination of best practices in the application of ventilation strategies it is necessary to address several questions:

1. What is ventilation?
2. How does it impact fire development and potential for extreme fire behavior?
3. How do ventilation strategies support incident priorities

Ventilation

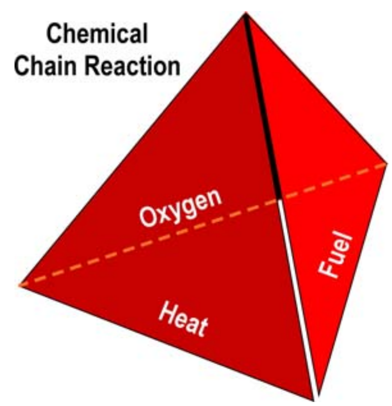
For many years, firefighters in the United States were taught that ventilation is "the systematic removal of heat, smoke, and fire gases, and replacing them with cooler air (IFSTA, 2007, p. 541) Is this really true?

Ventilation is actually the exchange of the atmosphere inside a building with that on the outside. This process goes on all the time and does not necessarily involve heat, smoke, and toxic gases. However, when a compartment fire occurs, ventilation involves supply of air (oxygen) to the fire and exhaust of smoke and hot gases. The extent of this process varies considerably, but if firefighters arrive and observe smoke issuing from the building, some ventilation is taking place. The extent and nature of ventilation may change due to fire effects (e.g., failure of window glass) or as a result of firefighting operations (e.g., opening a door to make entry or deliberately making an opening to change ventilation).

Ventilation and Fire Development

Ventilation and changes in ventilation have a major influence on compartment fire behavior. A simple combustion model such as the fire tetrahedron can be used to help understand why ventilation is such a critical factor.

Figure 2. Fire Tetrahedron



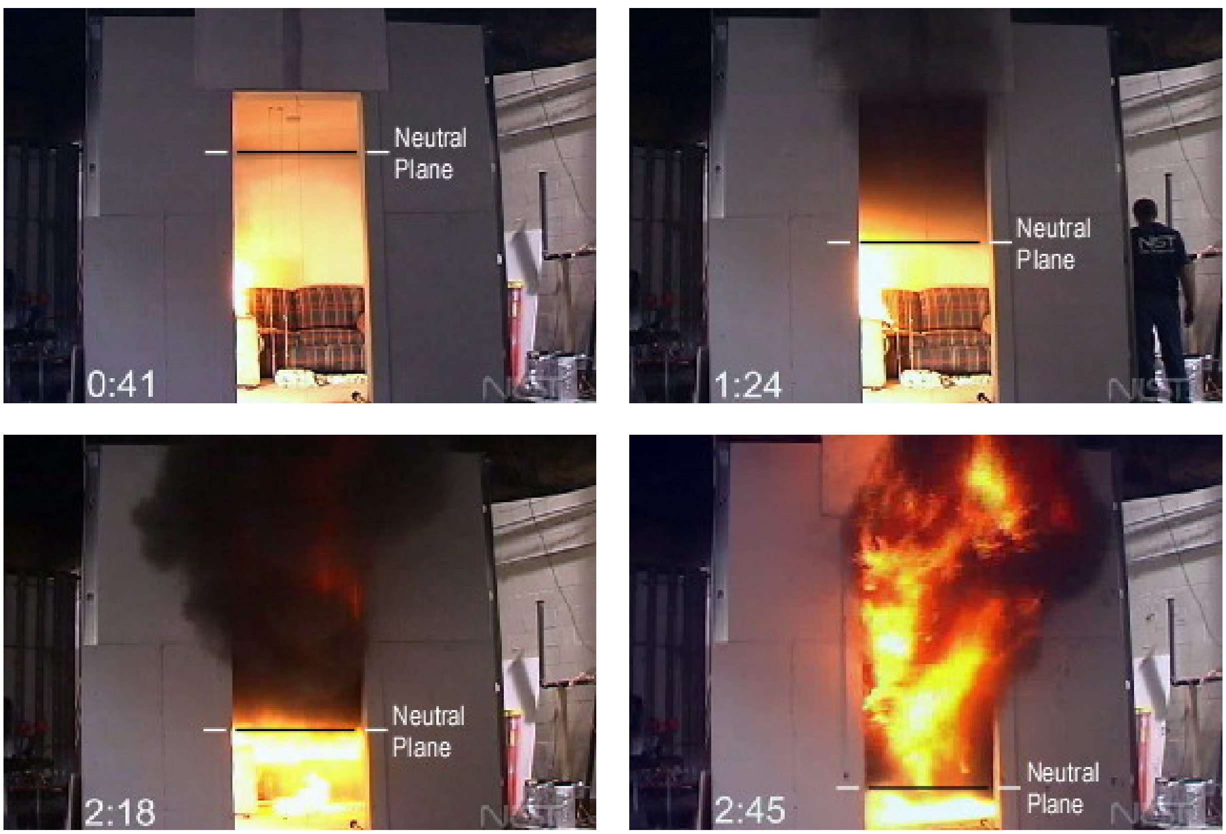
Combustion, as an oxidation reaction requires sufficient oxygen to react with the available fuel. When sufficient oxygen is available, fire development is influenced predominantly by fuel characteristics and availability. However, in a compartment fire oxygen may be limited by the compartments ventilation profile. When insufficient oxygen is available, the fire becomes ventilation controlled and fire development is influence predominantly by oxygen concentration.

When an incipient or growth stage fire is fuel controlled, a greater amount of ventilation will increase the heat release rate required to reach flashover and slow the time to flashover. This results from convective heat loss as hot smoke and gases exit the compartment. Thermal energy not retained within the compartment is not available to increase pyrolysis and the speed of the combustion reaction. In this situation, there is sufficient atmospheric oxygen to sustain flaming combustion, but loss of thermal energy from the compartment is limiting fire development. On the other side of this equation, less ventilation reduces the heat release rate required and speeds the time to flashover, unless the fire becomes ventilation controlled and enters the decay stage before reaching flashover.

Factors that influence the potential for a compartment fire to become ventilation controlled include the size of the compartment and compartmentation within the structure, the ventilation profile (including existing openings; leakage of air and smoke; and the heating, ventilation, and air conditioning system).

Given sufficient ventilation and fuel that will provide a sufficient heat release rate, a growth stage compartment fire will reach flashover. However, this does not mean that the fire will not become ventilation controlled. As illustrated in Figure 2, the lowering neutral plane at compartment openings reduces the size of the inlet providing air to the fire. Reduced inlet size may result in the fire becoming ventilation controlled.

Figure 3. Neutral Plane and Burning Regime



Note: Photos adapted from National Institute of Standards and Technology (NIST) *ISO-Room/Living Room Flashover*.

The fire tetrahedron can be used as a framework to examine the influence of increased air supply to a ventilation controlled compartment fire as illustrated in Table 1.

Table 1. Impact of Increased Air to a Ventilation Controlled Fire

Heat	Fuel	Oxygen	Chemical Chain Reaction
Heat Release Rate Increases		Oxygen Concentration Increases	Burning Rate Increases
Thermal Energy is Lost Due to Convection	Gas Phase Fuel (Smoke) Concentration Decreases		
	Gas Phase Fuel and Smoke Mix at the Hot Gas Layer Interface		

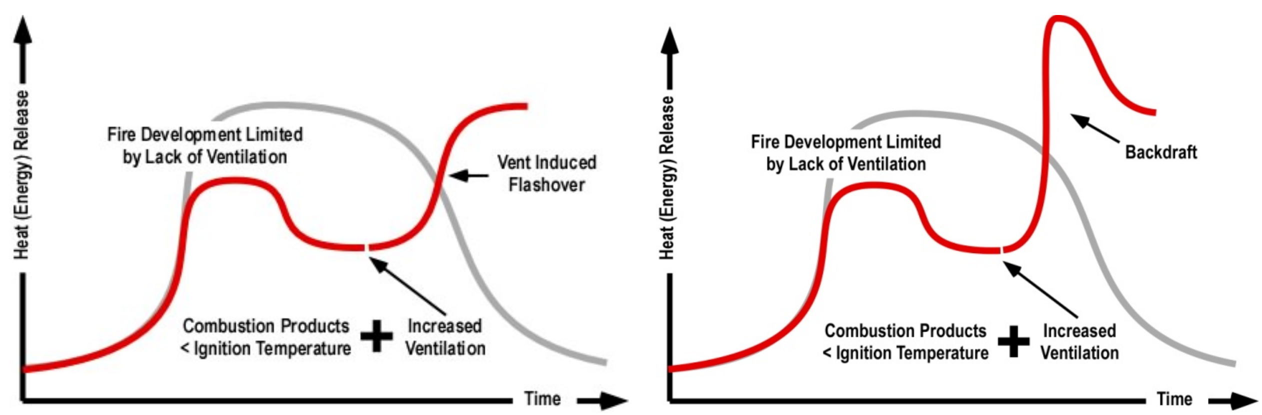
Most fires that progress beyond the incipient stage are ventilation controlled at the point where the fire department arrives. It is essential that firefighters recognize that changes in the ventilation profile have the potential to cause significant changes in fire behavior.

Ventilation Induced Extreme Fire Behavior

The potential for extreme fire behavior under ventilation controlled decay conditions is discussed at greater length in *Extreme Fire Behavior: Understanding the Hazards* (Hartin, 2008). However, it is important to review and reinforce how changes in ventilation profile can impact ventilation induced flashover and backdraft.

The primary difference between ventilation induced flashover and backdraft is the speed with which the heat release rate increases. Backdraft involves a deflagration (explosion) resulting in an extremely rapid and transient release of energy. On the other hand, ventilation induced flashover involves a rapid transition of a ventilation controlled fire to the fully developed stage with a sustained increase in heat release rate (as illustrated in Figure 3).

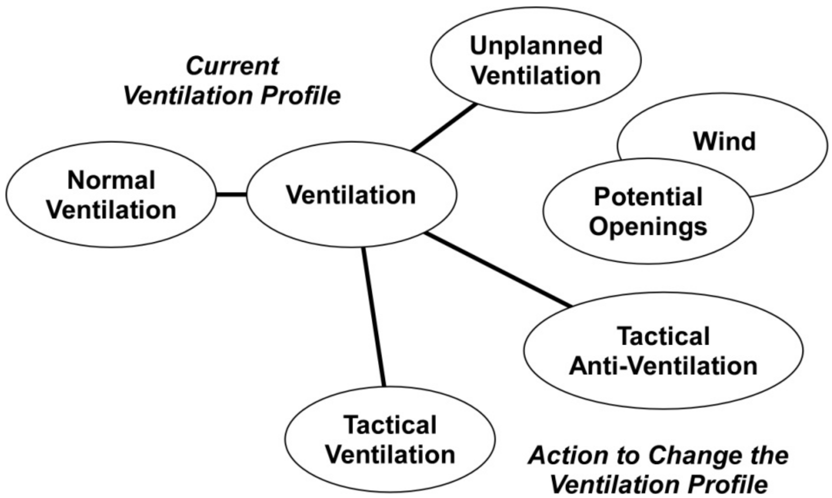
Figure 4. Ventilation Induced Extreme Fire Behavior



Changes to the Ventilation Profile

As previously mentioned, the ventilation profile may change for a variety of reasons. Figure 5 illustrates the three ways in which the ventilation profile may change 1) unplanned ventilation as a result of fire effects or human action, 2) tactical ventilation, or 3) tactical anti-ventilation.

Figure 5. Ventilation Concept Map



Normal ventilation involves the exchange of air inside a structure with outside air. As a fire develops, this exchange provides to support combustion and allows some smoke to escape. As previously discussed, air inside the structure and this normal building ventilation has a significant impact on fire development. One way in which this ventilation profile can change is unplanned ventilation due to human action or fire effects. For example, occupants exiting the structure leaving a door or window open or the fire may cause window glazing to fail due to temperature differential on the two sides of the glass surface. In addition to these causes of unplanned ventilation, firefighters making entry or performing unplanned or uncoordinated ventilation can also create undesirable changes in the ventilation profile. In addition to unplanned openings, wind can be a significant factor when the ventilation profile changes by increasing the volume of air supplied to the fire and/or creating draft effects.

While appropriate and planned changes in ventilation can significantly improve conditions inside the building, inappropriate or unplanned ventilation can adversely impact conditions and speed fire development. It is essential to anticipate potential changes to the ventilation profile and their effect on fire behavior.

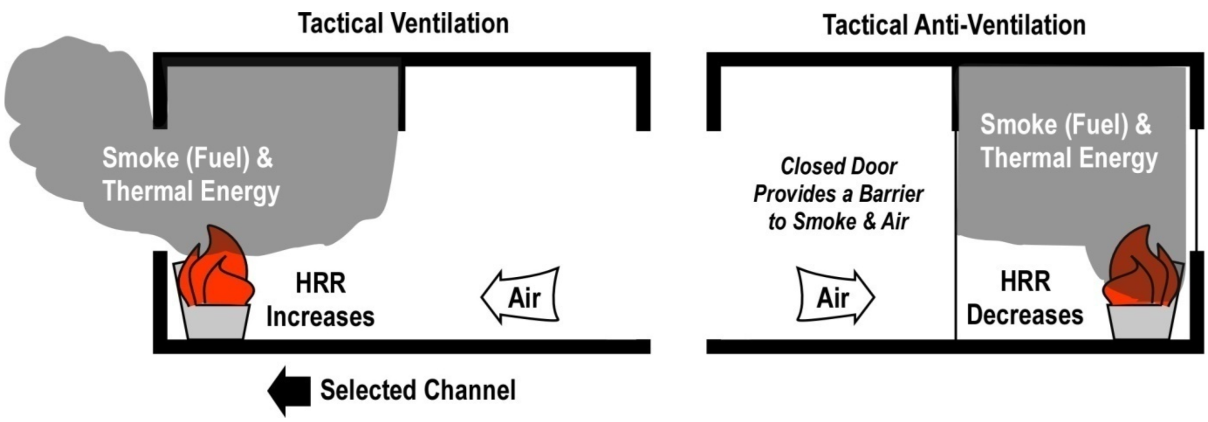
Managing Changes to Ventilation

While unplanned ventilation can have significant adverse impact on fire development, appropriate changes in ventilation profile can improve tenability; increase the safety of occupants, and firefighters, and aid in the effectiveness of fire control operations. As discussed earlier in this paper, there are two fundamental strategies for changing ventilation profile, tactical ventilation and tactical anti-ventilation.

Tactical Ventilation: Planned and systematic removal of heat, smoke, and fire gases and introduction of fresh air. Tactical ventilation is accomplished by using exhaust and inlet openings to create a selected channel for the flow of hot smoke and fire gases and air.

Tactical Anti-Ventilation: Planned and systematic confinement of heat, smoke, and fire gases and exclusion of fresh air. Tactical anti-ventilation is accomplished by closing openings (or keeping openings that are already closed in that position) or pressurizing adjacent compartments to prevent smoke infiltration.

Figure 6. Fundamental Strategies



Strategic and Tactical Decision-Making

When considering action to change the ventilation profile, it is useful for firefighters to keep in mind the advice of a old Japanese proverb: “Vision without action is a daydream. Action without vision is a nightmare.” In firefighting operations, strategies are what will be done and tactics are how the strategies will be accomplished. Both strategies and tactics must be based on the problems presented by the incident.

Consider how tactical ventilation and anti-ventilation influence fire behavior and the environment inside the building. Changes in the ventilation profile can influence fire development, potential for extreme fire behavior, and tenability. The complexity of ventilation decision making is rooted in interrelated and sometimes conflicting outcomes. For example, horizontal ventilation may raise the level of the hot gas layer, temporarily increasing tenability, but (without rapid fire control) the resulting increase in heat release rate may result in a ventilation induced flashover. In other cases, the desired tactic may require more time than is available. Vertical ventilation can have a significant positive impact in many cases, but time is required to access the roof and make the necessary opening. If roof cutting is necessary, this time must be factored into the plan of action.

Purpose

The first decision in developing a ventilation plan is strategic. *What is the purpose of the ventilation strategy?* Ventilation strategies can support life safety and fire control tactical priorities. In many cases, tactical ventilation aids in fire control as well as reducing the risk to firefighters and building occupants.

- *Life Safety:* Ventilation actions taken to provide or maintain a tenable environment inside the building. This can include tactical ventilation to raise the hot gas layer and draw the fire away from firefighters and occupants or tactical anti-ventilation to confine the fire and smoke or limit fire growth.
- *Fire Control:* Ventilation actions to support fire control fire limits fire spread by drawing heat in a specific direction, frequently away from uninvolved fuel or tactical anti-ventilation to limit the flow of air to the fire (reducing heat release rate) or to confine the spread of smoke and fire.

Consider if removal of smoke and replacement with fresh air (tactical ventilation) an effective strategy or is confinement of smoke and limiting entry of air (tactical anti-ventilation) more appropriate. Frequently the answer is both, either sequentially (first one and then the other) or concurrently (in different parts of the building). After making these decisions, it's on to tactics. Table 2 outlines the critical questions in tactical decision making for tactical ventilation and tactical anti-ventilation.

Table 2. Ventilation Decision-Making

Tactical Ventilation	Tactical Anti-Ventilation
• Direction and Location?	• Location?
• Method?	• Method?
• Sequence?	• Sequence?

Tactical Ventilation Decisions

Direction and Location: In what direction should the smoke and heat be moved? The first part of answering this question is to determine if horizontal or vertical ventilation is indicated. The second is determining the location of the exhaust opening (where smoke will be discharged) and the inlet opening (where air will be introduced).

Method: In many cases, tactical ventilation may be accomplished using the pressure and buoyancy of the hot smoke and gases inside the structure along with ambient wind conditions. This is referred to as natural ventilation. However, this is not always adequate to accomplish our objectives. Assisted ventilation involves adding energy through mechanical or hydraulic means to influence the air track. This typically involves use of a positive pressure fan (blower) to introduce air at the inlet opening to create a positive pressure or discharging a fog stream through the exhaust opening to create a negative pressure.

Sequence: Ventilation tactics must be appropriately sequenced in relation to fire control actions. Tactical ventilation must not be performed prior to placement of hoselines to deal with the increased heat release rate that will result from additional air supplied to the fire. However, positive pressure ventilation in conjunction with fire attack (positive pressure attack) requires that ventilation be performed prior to making entry into the structure. Negative pressure ventilation should be performed after fire control (as you are working at the exhaust opening).

Often, tactical anti-ventilation and tactical ventilation are used in sequence. Door control may be maintained prior to and after entry and tactical ventilation implemented after fire control has been accomplished. In other cases, increased ventilation may result from making entry through a window for search, and anti-ventilation used (close the door to the compartment) to limit its effect to that uninvolved, but smoke logged compartment.

Tactical Anti-Ventilation Decisions

Location: Effective use of tactical anti-ventilation requires identification of the location of inlet openings and potential barriers to movement of air and smoke. One critical opening is the entry point for firefighting and rescue operations. However, it is also important to think about building compartmentation (location of doors) and potential openings where unplanned (e.g., fire caused) ventilation may occur.

Method: In many cases, anti-ventilation will be a simple as maintaining door control at the point of entry (closing the door to as great an extent as possible after firefighters and hoselines have been deployed to the interior of the building. In other cases, it may involve closing interior doors to limit movement of smoke and air. Windows that have failed to fire effects present a greater challenge. However, research is currently underway to explore options for controlling this type of opening (in high-rise buildings). In March 2008 National Institute of Standards and Technology and the Fire Department of the City of New York (FDNY) conducted tests of a device to control inlet openings in wind driven high-rise fires (see Figure 7).

Figure 7. Prototype Wind Control Device

Note: Photo from *NIST Evaluates Firefighting Tactics in NYC High-rise Test*

Sequence: As with tactical-ventilation, anti-ventilation actions must be sequenced with fire control (i.e., before, during, or after fire control is established).

Summary

Effective ventilation can reduce the potential for extreme fire behavior and can limit or channel fire spread in a specific direction. However, Ineffective and inappropriate ventilation can cause extreme fire behavior or may spread the fire in an undesired direction.

Actions taken to influence (maintain or change) the ventilation profile must be based on knowledge of their influence on fire behavior and the environment inside the building as well as coordinated with other tactical operations.

Effective and appropriate ventilation tactics in coordination with fire attack result in:

- A more survivable environment
- Faster firefighting operations
- Limitation of fire spread
- Reduced extreme fire behavior
- Less property damage

International best practices can be drawn from the philosophical differences between the fire services of the United States, Europe, and Australia. Safety and effectiveness of fireground operations can be improved if the following considerations are addressed in the selection and implementation of ventilation strategies and tactics:

- Base ventilation decision-making on an understanding of fire dynamics.
- Recognize and address the influence of both sides of the ventilation equation: Smoke and Air
- Anticipate the impact of unplanned ventilation due to fire effects
- Integrate fire control and ventilation strategies.

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