

After a fire has reached its peak heat release rate, it will decline after some period of time. At this point, most of the available fuel has typically been burned and the fire will slowly decrease in size. The length of the decay phase depends on what type of fuel is available, how complete was the combustion of the fuel, how much oxygen is present in the compartment, and whether any type of suppression is occurring. The burning rate of liquid fuels is on the order of $50 \text{ g/m}^2\text{-s}$, with an associated energy release rate per unit surface area of approximately $2,000 \text{ kW/m}^2$. The burning rate per unit area of information is useful to estimate the duration of a fire involving a particular fuel spread over a specified area.

A.2.2 Stages of Fire Development

Generally, fires are initiated within a single fuel object. The smoke produced from the burning object is transported by a smoke plume and collects in the upper portion of the space as a layer. The smoke plume also transports the heat produced by the fire into the smoke layer, causing the smoke layer to increase in depth and also temperature. This smoke layer radiates energy back to unburned fuels in the space, causing them to increase in temperature.

Fire spreads to other objects either by radiation from the flames attached to the originally burning item or from the smoke layer. As other objects ignite, the temperature of the smoke layer increases further, radiating more heat to other objects. In small compartments, the unburned objects may ignite nearly simultaneously. This situation is referred to as “flashover.” In large compartments, it is more likely that objects will ignite sequentially. The sequence of the ignitions depends on the fuel arrangement, and composition and ventilation available to support combustion of available fuels.

A.2.3 Behavior of Fully Developed Fires

A fully-developed fire is one that reaches a steady state burning stage, where the mass loss rate is relatively constant during that period. The equilibrium situation may occur as a result of a limited ventilation supply (in ventilation controlled fires) or due to characteristics of the fuel (fuel-controlled fires).

If the rate of mass burning based on the incident heat flux and fuel characteristics (see Section A.2.1) exceeds the amount that can be supported by the available air supply, the burning becomes ventilation controlled. Otherwise, the fire is referred to as being fuel controlled. The ventilation air for the fires may be supplied from openings to the room, such as open windows or doors, or other sources such as HVAC systems.

Given that the heat released per unit of oxygen is a relatively constant value of 13.1 kJ/g for common fuels, the air supply required to support fires of a particular heat release rate can be determined. For every 1 MW of heat release rate, 76 g/s of oxygen is consumed. Considering that air is 21 percent oxygen, this flow of oxygen requires a flow of $0.24 \text{ m}^3/\text{s}$ (500 cfm) of ambient air. In the case of WTC 1 and WTC 2, for a 3-GW fire, a flow of $1,500,000 \text{ cfm}$ of air was required to support that fire. That airflow would have been supplied via openings in the exterior wall and the shaft walls.

Most of the research on fully-developed fires has been conducted in relatively small spaces with near-square floor plans. In such cases, the conditions (temperature of the smoke and incident heat on the enclosure) are relatively uniform throughout the upper portion of the space. However, Thomas and Bennetts (1999) have documented differences in that behavior for ventilation controlled fires in long, thin spaces or in large areas. In such cases, the burning occurs in the fuel nearest to the supply source of air. Temperatures are observed to be greatest nearest to the supply source of air.

In large or complex buildings, the incident flux on the structural elements is expected to vary over the entire space of fire involvement. A range of developing numerical models have the ability to compute the variation of the fire imposed heat flux on a 3-dimensional grid. The Fire Dynamics Simulator from the