http://www.nist.gov/fire/fire_behavior.cfm

Research Areas

Fire Fighting Technology

Electronic Safety Equipment

Fire Dynamics

Firefighter Fatality & Injury Studies

Fire Fighting Tactics

Fire Forensics

Fire Protection

Personal Protective Equipment

Staffing Studies

Structural Collapse

Wind Driven Fires

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Fire Dynamics

Fire Dynamics

Fire Dynamics is the study of how chemistry, fire science, material science and the mechanical engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior. In other words, Fire Dynamics is the study of how fires start, spread and develop. But what exactly is a fire?

Defining Fire

Fire can be described in many ways - here are a few:

- NFPA 921: "*A rapid oxidation process, which is a chemical reaction resulting in the evolution of light and heat in varying intensities.*"
- Webster's Dictionary: *"A fire is an exothermic chemical reaction that emits heat and light"*

Fire can also be explained in terms of the Fire Tetrahedron - a geometric representation of what is required for fire to exist, namely, *fuel*, *an oxidizing agent*, *heat*, and *an uninhibited chemical reaction*.

Measuring Fire

Heat Energy is a form of energy characterized by vibration of molecules and capable of initiating and supporting chemical changes and changes of state (NFPA 921). In other words, it is the energy needed to change the temperature of an object - add heat, temperature increases; remove heat, temperature decreases. Heat energy is measured in units of Joules (J), however it can also be measured in Calories (1 Calorie = 4.184 J) and BTU's (1 BTU = 1055 J).

Temperature is a measure of the degree of molecular activity of a material compared to a reference point. Temperature is measured in degrees Farenheit (melting point of ice = 32 º F, boiling point of water = 212 º F) or degrees Celsius (melting point of ice = 0 º C, boiling point of water = 100 º C).

º C	º F	Response
37	98.6	Normal human oral/body temperature
44	111	Human skin begins to feel pain
48	118	Human skin receives a first degree burn injury
55	131	Human skin receives a second degree burn injury
62	140	A phase where burned human tissue becomes numb
72	162	Human skin is instantly destroyed
100	212	Water boils and produces steam
140	284	Glass transition temperature of polycarbonate
230	446	Melting temperature of polycarbonate
250	482	Charring of natural cotton begins
>300	>572	Charring of modern protective clothing fabrics begins
>600	>1112	Temperatures inside a post-flashover room fire

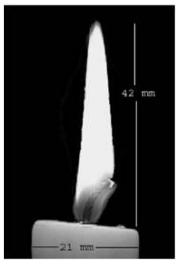
Heat Release Rate (HRR) is the rate at which fire releases energy - this is also known as *power*. HRR is measured in units of Watts (W), which is an International System unit equal to one Joule per second. Depending on the size of the fire, HRR is also measured in Kilowatts (equal to 1,000 Watts) or Megawatts (equal 1,000,000 Watts).

Heat Flux is the rate of heat energy transferred per surface unit area - kW/m^2.

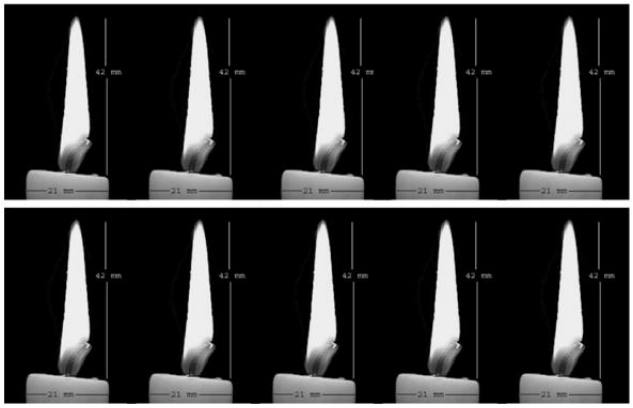
1	Sunny day
2.5	Typical firefighter exposure
3-5	Pain to skin within seconds
20	Threshold flux to floor at flashover
84	Thermal Protective Performance Test (NFPA 1971)
60 - 200	Flames over surface

Temperature vs. Heat Release Rate

One candle vs. ten candles - same flame temperature but 10 times the heat release rate!



HRR: ~ 80 W
Temperature:
500 C - 1400 C
(930 F - 2500 F)



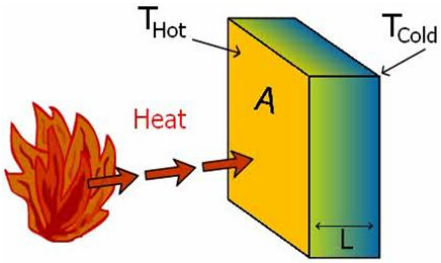
HRR: ~ 800 W

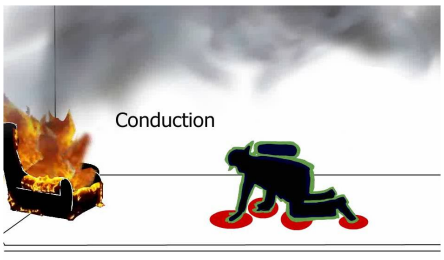
Heat Transfer

Heat transfer is a major factor in the ignition, growth, spread, decay and extinction of a fire. It is important to note that heat is *always* transferred *from* the hotter object *to* the cooler object - heat energy transferred to and object increases the object's temperature, and heat energy transferred from and object decreases the object's temperature.

CONDUCTION

Conduction is heat transfer within solids or between contacting solids.





The governing equation for heat transfer by conduction is:

$$\dot{q} = \frac{kA(T_{Hot} - T_{Cold})}{L}$$

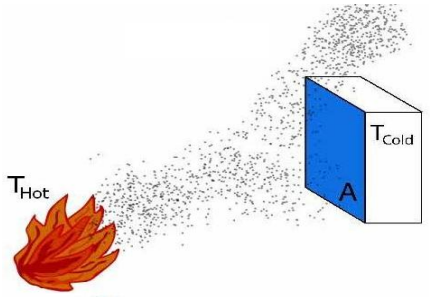
Where *T* is temperature (in Kelvin), *A* is the exposure area (meters squared), *L* is the depth of the solid (meters), and *k* is a constant that unique for different materials know as the *thermal conductivity* and has units of (Watts/meters*Kelvin).

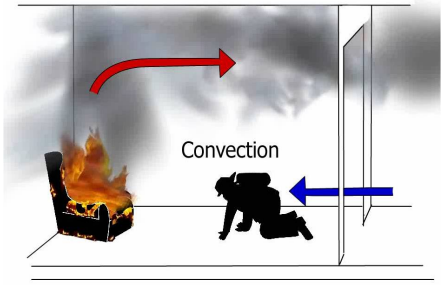
Thermal Conductivity of Common Materials

Copper = 387	Gypsum = 0.48
Steel = 45.8	Oak = 0.17
Glass = 0.76	Pine = 0.14
Brick = 0.69	PPE = 0.034 - 0.136
Water = 0.58	Air = 0.026

CONVECTION

Convection is heat transfer by the movement of liquids or gasses.





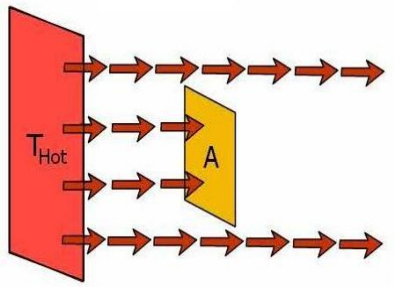
The governing equation for heat transfer by convection is:

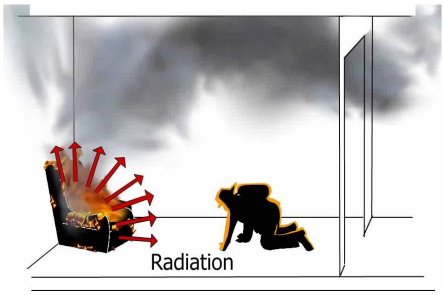
$$\dot{q} = h(T_{Hot} - T_{Cold})A$$

Where *T* is temperature (in Kelvin), *A* is the area of exposure (in meters squared), and *h* is a constant that is unique for different materials known as the *convective heat transfer coefficient*, with units of W/m^2*K. These values are found *empirically*, or, by experiment. For free convection, values usually range between 5 and 25. But for forced convection, values can range anywhere from 10 to 500.

RADIATION

Radiation is heat transfer by electromagnetic waves.





The governing equation for heat transfer by radiation is:

$$\dot{q} = (\varepsilon\alpha T_{Hot}^4)A$$

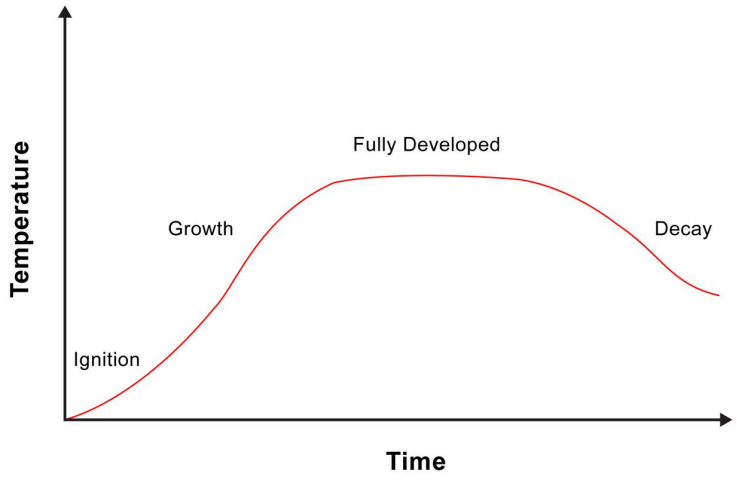
(a measure of how quickly a material will adjust it's temperature to the surroundings, in meters squared per second) and ε is the emissivity (a measure of the ability of a materials surface to emit energy by radiation).

Fire Phenomena

Fire Development is a function of many factors including: fuel properties, fuel quantity, ventilation (natural or mechanical), compartment geometry (volume and ceiling height), location of fire, and ambient conditions (temperature, wind, etc).

Traditional Fire Development

The Traditional Fire Development curve shows the time history of a fuel limited fire. In other words, the fire growth is not limited by a lack of oxygen. As more fuel becomes involved in the fire, the energy level continues to increase until all of the fuel available is burning (fully developed). Then as the fuel is burned away, the energy level begins to decay. The key is that oxygen is available to mix with the heated gases (fuel) to enable the completion of the fire triangle and the generation of energy.

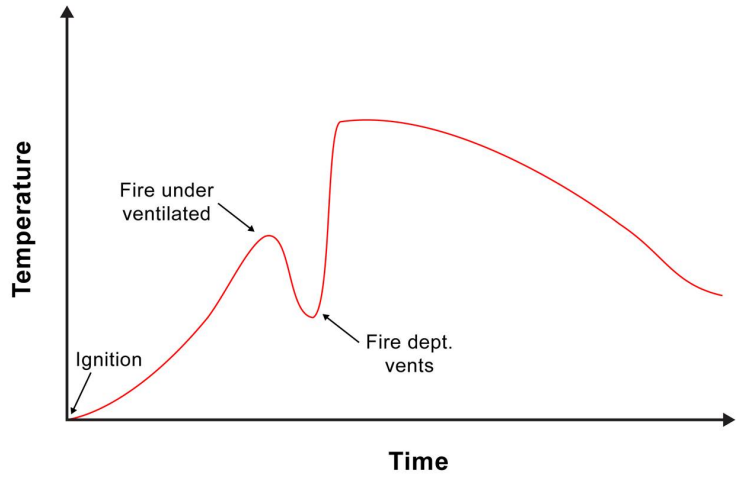


Watch

Windows: Traditional Fire Development in a Compartment Fire
Mac: Traditional Fire Development in a Compartment Fire

Fire Behavior in a Structure

The Fire Behavior in a Structure curve demonstrates the time history of a ventilation limited fire. In this case the fire starts in a structure which has the doors and windows closed. Early in the fire growth stage there is adequate oxygen to mix with the heated gases, which results in flaming combustion. As the oxygen level within the structure is depleted, the fire decays, the heat release from the fire decreases and as a result the temperature decreases. When a vent is opened, such as when the fire department enters a door, oxygen is introduced. The oxygen mixes with the heated gases in the structure and the energy level begins to increase. This change in ventilation can result in a rapid increase in fire growth potentially leading to a flashover (fully developed compartment fire) condition.



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