ILLINOIS FIRE SERVICE INSTITUTE
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Instructors: Rich Stack
Tim Walsh

Where There's Smoke There's Fire Behavior

SOBERING STATISTICS

Fire kills more Americans each year than all-natural disasters combined

U.S. fire departments responds to a fire every 17 seconds

Fires cause an average of one death every 2 ½ hours

IS THE FIRE SERVICE READY FOR BATTLE?

The Fire Service

The Military

HOW DO WE WIN THE BATTLE?

Knowledge

Of fire behavior

Of smoke behavior

Of building construction

The more information we have, the better decisions we make

KNOWLEDGE OF FIRE BEHAVIOR

- Without a doubt, the lack of knowledge the fire service has for fire behavior is one of the biggest causes of firefighter fatalities in both the training environment as well as on the fire-ground
- Fire Behavior
- Smoke Behavior
- Building Construction

DO WE UNDERSTAND FIRE BEHAVIOR?

DO WE UNDERSTAND SMOKE?

DO WE UNDERSTAND FIRE BEHAVIOR AND BUILDING CONSTRUCTION?

THE FIRE SERVICE MUST HAVE RESPECT AND AN UNDERSTANDING OF FIRE BEHAVIOR

- Fire

Rapid oxidation of combustible materials accompanied by a release of energy in the form of heat and light

- Combustion

An exothermic chemical reaction that is a self-sustaining process of rapid oxidation of a fuel, that produces heat and light

FIRE BEHAVIOR

- Fire Triangle

    Heat

    Oxygen

    Fuel

    Non-flaming combustion

- Fire Tetrahedron

    Heat

    Oxygen

    Fuel

    Chemical chain reaction

    Flaming combustion

COMBUSTION

- An oxidation reaction
- Several factors need to be present

    Fuel

Oxygen

- ❖ Fuel can range from a forest to home furniture, or from crude oil to gasoline.
- ❖ A fuel can present itself in any physical form

Gases

Liquids

Solids

OXYGEN

- ❖ Usually originates from surrounding air

Normal air 21%

- ❖ If the oxygen concentration is lowered, the combustion will be hindered and eventually stop
- ❖ When oxygen level drop below 14%, flaming combustion will become a problem and the fire will take on a stage of smoldering
- ❖ The flaming combustion stops
- ❖ 14% Oxygen

The combustion process is incomplete

This will increase the amount of smoke, fire gases and other flammable combustion products that will fill the structure

Most fires will become ventilation controlled and burn with 50% less efficiency

- ❖ Below 14% Oxygen

When opening the building up what are you doing to the fire behavior?

Will the fire increase in intensity?

What are the hazards?

HEAT TRANSFER

- ❖ Accomplished by three means, usually simultaneously
  - Conduction
  - Radiation
  - Convection

PHYSICAL SCIENCE

- ❖ Conduction - the point-to-point transmission of heat energy. A result of direct contact w/ heat source
- ❖ Convection - the transfer of heat energy by the movement of heated liquids or gases.

Direct Flame Contact

- ❖ Radiation - the transmission of energy as an electromagnetic wave without an intervening medium.

Such as light waves

WHAT DO WE SEE WHEN WE LOOK AT A FLAME?

- ❖ A Chemical Reaction
- ❖ Numerous Chemical Reactions
- ❖ The Release of Energy
- ❖ Thermal Radiation and Visual Radiation

THE CANDLE

- ❖ Energy in the form of heat from a match melts the wax in the wick
- ❖ As the wax heats up, long chain hydrocarbons break apart and are drawn up through the wick
- ❖ The flame and the vapor get hotter and breaks down
- The reaction produces

    Water

    Soot

    Carbon Dioxide

    More Heat

- Soot

  Absorbs some of the energy and gives off the yellow light we see

  The remaining heat is radiated back onto the candle causing more wax to melt

WHAT'S BURNING?

  - It's not the wick or the candle burning
  - It's the gas the hot wax is giving off
  - It reacts with the air in a simple reaction
  - All materials will behave this way

WILL SMOKE BURN?

- Products of Combustion
  - SMOKE
  - *10% visible*
  - *90% you can't see*
  - *Carcinogens both Acute and Chronic*

WHY DID THE SMOKE IGNITE?

- Ignition Temperature

The lowest temperature a fuel will off-gas an ignitable mixture that can self-ignite

- Fire Point

The lowest temperature a fuel will off-gas an ignitable mixture that will ignite and continue to burn given an ignition source

IGNITION

- *Flammable (explosive) range* - the range of concentrations of the fuel vapor and air (oxidizer).
- *Lower flammable limit (LFL)* - the minimum concentration of fuel vapor and air that supports combustion.
- *Upper flammable limit (UFL)* - the concentration above which combustion cannot take place.

DENSITY - A MEASURE OF HOW TIGHTLY THE MOLECULES OF A SOLID SUBSTANCE ARE PACKED TOGETHER.

- Matter
- Impact of Density on HRR
- How Will this Affect A Structure Fire?

PHASES OF FIRE

- Ignition
- Growth
- Flashover
- Fully Developed
- Decay

HOW WILL EACH PHASE OF FIRE IMPACT?

- FF Safety and Decisions?
- Citizen Safety?
- Structural Environment?
- Smoke Behavior?

IGNITION SOURCES PHASES OF FIRE

Piloted - caused by a spark or flame.

Nonpiloted - caused when a material reaches its ignition temperature as the result of heating.

Ignition Phase

- Early stage of a fire during which fuel and oxygen are virtually unlimited
- Heat release is increasing
- Fire under or up to the ceiling

Growth Phase

- Oxygen supply will have a direct effect on the speed of growth and size of fire
- Fuel size and amount will determine size and rate of fire spread
- Container size will influence how well heat dissipates
- Insulation of the container will influence how well heat will be radiated back into unburned areas
- Thermal plume is obvious, reaching ceiling and moving laterally.
- Plenty of air
- Detached gas phase possibly resulting in some form of rapid fire
- Super-heated fire gases
- MOST HOSTILE FIRE PHENONMENA THAT CAN INJURE OR KILL
- FIREFIGHTERS ARE BEING SET UP DURING THIS PHASE

Flashover

- The sudden full-room involvement in flame. Flashover is caused by thermal radiation feedback.
- During a fire in a room, the heat is absorbed into the ceiling and walls and re-radiated downward, gradually heating the combustible gases and contents to their ignition temperatures, and the room and its contents simultaneously ignite

WHY FLASHOVER TRAINING?

- Allows firefighters to recognize the signs of flashover
- Provides firefighters with techniques to possibly give them time to escape a flashover
- To save firefighters from injury and death from flashover

WARNING SIGNS OF A FLASHOVER

- Free Burning

Open flame production which heats the materials and contents and allows the production of fire gases

- Heat Buildup

In a smoke-filled room (Very hot smoke that forces a firefighter to crouch down when entering a building signals a flashover danger. The lower you are forced to crouch down, the greater the chance of a flashover

Warning Signs Of A Flashover

- Thick, Dark Smoke

Large amounts of fire gases being produced and heated by redirected heat

- Rollover

Sporadic small flashes of flame mixed with smoke seen just before the flashover occurs

Before entering a smoke-filled room, firefighters should check the smoke coming out of the door or windows for signs of rollover

FLASHOVER SURVIVAL TECHNIQUES

- Recognize the warning signs of heat and rollover
- Avoid disorientation/use proper search techniques
- Enter and leave through the same door
- Use pre-fire planning
- Carry a flashlight at all times
- Wear all protective clothing and equipment

THE POINT OF NO RETURN

- Without a hose line, a firefighter can travel, on average, 2 ½ feet per second in full protective gear
- The firefighter has approximately 2 seconds to exit when a flashover occurs
- There is a possibility of escape if a firefighter is 5 feet or less from a door

CLASSIC WARNING SIGNS OF AN IMPENDING EVENT

- Heavily smoke stained or cracked window glass (hard to see with new windows)
- Yellow or orange flames seen in the overhead, possibly as rollover detaching themselves from the main fire
- Doors or windows being forced open causing air to rush in and feed the fire
- High velocity smoke exiting a doorway or window
- A sudden change in color of smoke, particularly darkening
- A sudden change in heat conditions, forcing crews to crouch low
- A sudden lowering of the smoke layer
- A repeated rising and lowering of the smoke layers
- Pulsating smoke, smoke seen pushing out of openings, or under pressure
- What is the Hazard of the Decay Stage

THE STAGES OF FIRE

THE SPEED OF FIRE

- Slow developing fires

Double in size every 120 seconds

- Medium developing fire

Double in size every 60 seconds

- Fast developing fires

Double in size every 30 seconds

- Ultra-fast developing fires

Double in size every 15 seconds

FIRE LOADING

- Fires fought in the 1970's would reach 1,500 degrees after about 15 minutes
- Because of fire loading characteristics and plastic materials fire fought now reach temperatures more than 2000 degrees in about 3 minutes

THE STRUCTURE FIRE PERSPECTIVE

- A large non-compartmented area involved in fire can double in size every 15 seconds
- Example

Open plan 20,000 sq. ft filled with fast burning upholstered furniture, fire involving 500 sq. ft double in size every 15 seconds

Within a minute of committing our first in engine company, this fire may have developed rapidly in area and intensity to involve over 2,000 sq. ft.

- The fire will develop so fast that it will be beyond the control and capability of a single 150 GPM line within 15 seconds of entry.

EFFECTS ON TODAYS FIRES

- Size of the fire load
- Type of fire load
- Size and location of the vent openings
- Size of the door opening
- Direction and force of exterior wind directions

THE FIRE SERVICE MUST HAVE RESPECT AND AN UNDERSTANDING OF BUILDING CONSTRUCTION

WHY IS BUILDING CONSTRUCTION IMPORTANT?

- FIRE BEHAVIOR AND BUILDING CONSTRUCTION

What Is Burning?

How they influence each other?

What do we do!!!!

Applying Appropriate Tactics.

WHY SHOULD WE UNDERSTAND BUILDING CONSTRUCTION?

BUILDING CONSTRUCTION: KNOWLEDGE HELPS

- Occupancy Type
- Entanglement Hazards
- Floor Layout
- Fuel Load
- Fire Behavior and Extension Probabilities
- Entry and Egress
- Fire Attack and Control

BUILDING CLASSIFICATIONS

- *Type One – Fire Resistive*

Protected structural elements and is the most fire-resistive category.

Noncombustible fire-rated materials are coated or encased for protection against normal fire conditions.

Structural elements are commonly encased in concrete or fire-rated drywall or sprayed with a fire-rated material so that the framing materials are not immediately exposed to fire.

- *Type Two – Non-Combustible*

Building materials that will not directly contribute to the development of fire or any flame spread

Few fire-resistive qualities and is susceptible to early failure

Popular in industrial and commercial facilities because of the reduced construction costs

Potential for early collapse, clearly establish collapse zones based on the height of the structure.

Unprotected steel will expand as it is heated and begins to lose strength at 1,100°F; at 1,500°F

- *Type Three – Ordinary*

Combination of combustible and noncombustible features.

Termed "Main Street USA."

Exterior walls are protected by a noncombustible material and the fire resistance of the interior depends on building's age

Recognize and fully evaluate the presence of void spaces which is typical of this construction type.

- *Type Four – Heavy Timber*

Wooden structural elements, when properly maintained, not prone to early collapse

Large-cross-sectional lumber used in walls, ceilings, floors, and roof assemblies makes it very sturdy

- *Type Five – Wood Frame*

BUILDING CONSTRUCTION

- The introduction of synthetics and engineered building systems has changed the residential structure fires
- Residential structure fires are declining
- Firefighter injuries and deaths have increased
- The fire service is injuring and killing more firefighters each year at less fires

Residential Structure Fires

- Are only 25% of all fires in the USA

83% of fire deaths

77% of fire injuries

64% of direct dollar losses

- Residential fires account for more firefighter fatalities than any other structure

The Growing Housing Trend

- 2005 Record setting year in residential construction
- 1950 Average house size 983 square feet
- 2005 Average house size 2480
- 1950 Fuel load compared to 2005 fuel load

Why more square footage?

- Keeping up with the Jones'
- Engineered building systems
- The use of trusses has reduced the material cost of traditional full thickness lumber and the labor cost of installing materials
- Contractors can build larger structures for less

Interior Finishes

- The interior of structures has changed
- During the residential building boom following WWII interior bearing walls where built to support the upper floors and roofs of the structure

Serving as unintentional fire stops

Each bearing wall would have a door allowing the fire to be compartmentalized

- Roof trusses removed the need for bearing walls
- Flame spread throughout the structure

The Open Floor Plan

- Larger homes increase the risk that a firefighter will become disorientated or trapped inside the structure
- Larger homes require the firefighter to remain inside the structure longer

Large Floor Plans

- Additional fuel loads
- Fires in modern structures

Producing more heat

Spreading faster

Producing more smoke

- The fire loading is estimated at two times greater than it was in the 1940's

Fire Loading

- 1950's: 8,000 BTU per pound
- Today: 16,000 BTU per pound
- 1940's & 1950's

Hardwood flooring

The furniture was made of natural materials, cotton, wood and wool

- Copper water pipes and iron sewer pipes have been replaced with plastic pipes
- Tin duct work has been replaced with flexible supply ducts with a plastic wrapping thus Exposing firefighters to a deadly entanglement hazard caused by slinky like wire used in the flex duct
- Return air ducts have been replaced with cardboard wrapped in a thin reflective material
- Black iron gas pipe has been replaced with a flexible pipe with a plastic coating
- Electrical systems have changed dramatically

Home theaters

Home computers

- The additional wiring produces toxic smoke
- 1940's the average home used 1,100 KW per person
- 1990's the average home used 11,110 KW per person

The Changing Fire Load We Face

- The increased BTU's are resulting in a fast fire exposing more of the structure to its effects
- Faster moving fires requires more GPM to overcome the BTU's
- The additional GPM creates an additional live load in the structure
- The structures are already weakened by the fire

The GPM puts an additional strain on the structure

- Exterior Finishes & Features
- The structures have changed on the outside as well
- 2005: 64% of the homes built in Midwest had vinyl siding as its principal exterior material
- Vinyl siding has no fire rating and will often melt or catch fire when exposed to flames

Old School Construction Exterior Soffits

Exterior Soffits

- Roof rafters would extend down past the exterior walls to create an overhang
- Boards were placed between the rafters where they contacted the exterior wall (bird blocking)
- This construction of soffits served as a fire barrier

Stopping the spread of fire into the attic space

- Enclosed soffits

Less maintenance and increased ventilation in the attic

No bird blocking required

The fire can extend into the attic or roof area

Fire venting out windows or fires on the exterior can quickly enter the attic space taking control of the entire upper portion of the structure

Windows

- Improvements in windows have further complicated firefighter operations
- The double glass design of thermal windows contains the fire within the structure
- The fire burns longer and hotter before being detected
- The risk of flashover and backdraft increases
- The windows keep the heat in until the window fails allowing cool fresh air into the structure creating a fire ball

What Are We Crawling On?

What is below you (Lightweight Construction)?

WHY IS SMOKE BEHAVIOR IMPORTANT?

- It Can Tell You What is Happening inside the Structure.

What Is the Smoke Telling You?

- Four Key Factors of Smoke

<u>Volume</u>

Amount of fuel off-gassing or the fullness of the "Box"

Density

Quality of burning. Potential for event-

PERHAPS THE MOST IMPORTANT FACTOR-

The thicker the smoke the more dangerous it is

Velocity

How fast the smoke is leaving. Indicates pressure build up. Only volume and heat can cause pressure

Color

Degree of black/gray = which stage of heating and distance from the fire

Volume affected by the Size of the structure.

- Big Container
- Medium Container
- Small Container

How much smoke?

- Heavy
- Moderate
- Light

Where is the smoke coming from?

- One Window or Door
- Attic Area
- Entire Structure
- VOLUME

Reading the Smoke: Smoke leaving a building gives you info

Heavy Smoke

- Large Fire
- Large Fire Load

Moderate Smoke

- Possible Room and Content

Light Smoke

- Minor fire

- Clothes, paper, rubbish, Food on the stove

Velocity

Rate of Heat Release
Influence of Structure

- Size
- Internal Features

Slow or Fast Spread

- Wispy Lazy Smoke
- Pushing Under Pressure

Rapidly Moving Smoke is Hot

Velocity is the Most Important Factor

- Caused by Pressure and Heat
- Volume effected smoke *slows down* while exiting

  Smooth Laminar Flow (Still absorbing Heat)

- Heat effected smoke rises when exiting

  Turbulent Flow (not absorbing heat)

- Narrows down at fire location based on speed

The lower the velocity air intake THE GREATER THE FIRE

- The fire feeds on oxygen intake

Smoke color and Materials

Materials

- Paper or cloth
- Furniture
- Room and contents *(foam, rubber, plastics)*
- Wood elements of structure
- Complete Involvement of structure

Color of smoke

- Light gray
- Dark gray
- Dark gray to black
- Brown

- Very dark, almost black
- COLOR

Paper or Cloth

- Light gray

Furniture

- Dark gray
- COLOR

Room and Contents

- Dark gray to black
- ➢ Furniture
- ➢ Carpet
- ➢ Plastics
- ➢ Wall Coverings
- ➢ Paint
- COLOR

Wood Structural Components

- Brown smoke
- Indicates Early carbonization of wood
- Fire is in concealed spaces

Heat and Smoke Lifting Dust from Concealed Spaces

Complete Involvement

- ❖ Black Smoke
- ❖ Fire is consuming Contents and structure.
- ❖ May be a false read Due to plastics

Color Variations

Light Smoke

- As fuel begins to heat Further from the seat of the fire smoke is filtered as it moves thru the structure

Dark Smoke

- Closer to the seat of the fire.

Black Smoke

- Looks like black fire

- Heated fuel cloud which IS IGNITABLE

Will Smoke Explode?

- Density effected by incomplete combustion
    - Thick dense smoke is caused by particulates that have not burned yet.
- Density

Velvety, inky, shiny smoke is due to extremely high heat
The denser the smoke is the more DANGEROUS it is.

What Is the Smoking Telling You?

- Is there a possibility for Smoke Explosion or Backdraft?

Smoke Explosion

- Occurs when the colder gray smoke cloud ignites after congregating outside of its room of origin
- The results can be very unpredictable, and if the ignition occurs at the ideal mixture, the results can be a violent smoke gas explosion. (Fire Gas Ignition)

Backdraft

- Occurs when the flammable gases are ignited while at the upper region of the flammability range
- This can happen in rooms where the fire subsided because of the lack of oxygen

Smoke Explosion

- A smoke explosion is the brief flash of a pocket of gas that is at its flash point

This causes a rapid surge (expansion) of the remaining gases.

It can be forceful enough to lift firefighters.

- Signs include trapped gases that mix with air and continue to be heated

They just need a spark or flame to ignite

Flashpoint

- **What is the Hazard of the Decay Stage? *<u>Smoke Explosion !!!!!!!!</u>***

Remember What Is the Smoke Telling You?

Reading Smoke Hints

Turbulent Smoke

- Flashover or ignition imminent

Brown Smoke

- Structural elements burning

Black Smoke (Black Fire)

- Too rich to burn

Smoke with the same color and velocity leaving multiple opening

- Deep seated fire

Making Entry

Before opening the door ask these questions

Is the door hot to touch or blistered by fire?

Is this a door we need to open?

Is the hose line charged and are firefighters ready for attack?

Questions or Comments