FIRE INVESTIGATION
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PROBLEMS WITH FLASHOVER

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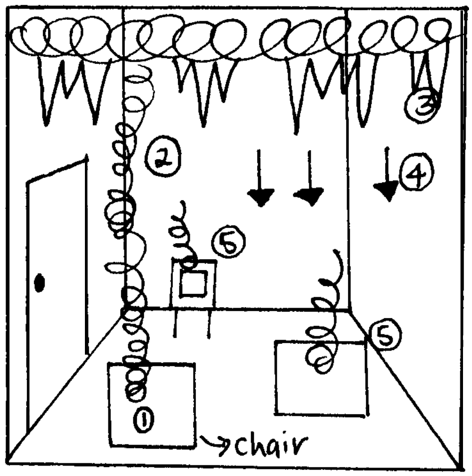
ABSTRACT

Flashover is defined as "a transition phase in the development of a contained fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space". The occurrence of flashover is an extreme form of fire behaviour. The various studies which have been made on the subject of flashover to learn what exactly causes flashover and how to fight them, have only recently commenced to be understood. For fire investigators, flashover is a 'new reality' which they have to consider in their work.

The following diagram shows the various stages in a typical room fire sequence.



1) When a fire is started on a chair, heat is given off by the fire decomposes the foam / fabric of the chair faster than the chair will burn.
2) Smoke, which is full of fuel, rises to the ceiling. As the smoke gets hotter, the three sides of the fire triangle (fuel, oxygen and heat) come together.
3) The rising smoke reaches flash point and ignites, and this is called a lean flashover. The fire runs across the ceiling.
4) The fire at ceiling level radiates heat downwards.
5) This heat decomposes everything combustible. At a critical temperature of approximately 600°C the room will flashover, and everything combustible will burst into flame.

There are various problems associated with flashover. The first of these is the high temperatures involved with flashovers. The extremely high temperatures involved with flashover are one of the problems, as they provide life-threatening situations for inhabitants of buildings and for fire fighters. When a room tire sequence is nearing flashover, or has already flashed-over, survival is not possible for humans due to the amount of toxic gases in the room atmosphere and also due to the extremely high temperatures present. Fire fighters can utilize breathing apparatus to combat the toxic gases, but the extremely high temperatures prevent them form being able to fight the fire.

The second problem is the speed of the spread of the flashover. With the occurrence of flashover, the transformation of flames being present at ceiling level to the ignition of all flammable items in the room is very rapid. Flashover usually means widespread and uniform destruction. In fires today, flashover tends to occur more rapidly and more often, due to the nature of the combustible materials with which modern furniture is made of.

The third problem is that there are several characteristics of flashover which may suggest arson, as new evidence is beginning to show. These include false low points which suggest multiple points of ignition, and burn patterns which may suggest the pouring of liquid accelerants. Also, if flashover occurs in a fire, it may destroy useful evidence of arson.

Another problem of flashover is the need for further and continued education and training in the area of flashover. This education and training is necessary for fire investigators, police services and fire fighters. With the various groups working together, fire fighters will establish better techniques to combat flashover and flashover-related fires, so as to decrease the number of human fatalities and injuries, and the amount and cost of property destruction.

The last problem is that of whether to ventilate or not. One way in which to prevent flashover is to ventilate, where the layer of hot gases escapes before the critical temperature is reached. On the other hand, if no ventilation is present (or is limited), the is starved, where the progress of the fire slows to a point where flashover will no longer occur. The problem arises in making a decision between the two.

Introduction

Flashover is defined as “a transition phase in the development of a contained fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space”. [7] The occurrence of flashover is an extreme form of fire behaviour. The various studies which have been made on the subject of flashover to learn what exactly causes flashover and how to fight them, have only recently commenced to be understood. For fire investigators, flashover is a ‘new reality’ which they have to consider in their work. [6]

“To try and understand what a flashover is, means having to understand the very nature of fire itself’. [151 Due to the difficulty associated with the understanding of flashovers, this essay will first discuss the sequence of a room fire, prior to and following, a flashover; so as to clearly define this phenomenon. Secondly, the different types of flashover will be discussed; and thirdly, the various problems associated with flashover will be entered into. The problems of flashover, to be discussed in the essay, include the high temperatures involved with flashovers; the rapid speed of the spread of flashovers; the linkage between flashover and arson; the need for further education and training in the area of flashovers; and the question of whether to ventilate or not when fighting fires.

Describing The Phenomenon Of Flashover

It is rather difficult to understand the occurrence of flashover, without first briefly describing the three stages of burning in a usual room fire, with flashover fitting into the second of these stages. Each stage has characteristic features and varied effects on the fuels in the room. The room described below is considered to have a normal fuel load. Please refer to the diagram in Appendix A, for further explanation of the descriptions provided.

1. Incipient /Beginning Stage

This stage begins with ignition. There is usually a 21% concentration of oxygen present in the surrounding air, and therefore if all the other elements necessary for combustion are present (that is, fuel and ignition), the fire can burn freely. The upper portion of the room is filled with the smoke and hot gases which are generated from the fire through convection. The contents of these gases depend on the fuels which are being burned, but they usually consist of carbon dioxide, water vapour, carbon monoxide, hydrogen, some sulphur dioxide and soot (carbon and other solids). Oxygen is continually being taken in at the bottom of the flames to sustain combustion, and due to this the concentration of oxygen in the air begins to fall to about 20%. If solid fuels are present above the flames, the flames are spread upward an outward through convection and direct flame contact. The overall temperature of the room does not begin to rise significantly during this stage. [l]

2. Progressive /Free-Burning Stage

The fire becomes stronger as it uses up more and more fuel and oxygen. The rate of oxygen consumption depends on how large the room is and how well the ceiling is insulated. The flames are further spread upwards and outwards from the initial fuel through convection, conduction and direct flame contact. Nearby materials reach their ignition temperatures and begin to burn. The concentration of oxygen in the air falls to approximately 18% and the ceiling temperature increases rapidly to 204-260°C. Also, the amount of smoke and hot gases increases and intensifies very quickly. These gases mix and form other gaseous compounds. It can be noted that the concentration of sulphur dioxide increases dramatically at this stage, especially if certain plastics are involved in the burning. [l] [3]

Further heat radiation from the flames brings other fuels to their ignition temperatures and the fire spreads laterally. The speed of the spreading depends on the closeness of the fuels and their physical arrangement in the room. The process of pyrolysis has now begun on most organic substances in the room. [1] [3]

The conditions at ceiling level of the room and at floor level of the room are very different during this stage. The concentration of oxygen is still fairly normal at floor level and temperatures are still quite cool. However, at ceiling level of the room, limited ventilation to the room results in the production of more incompletely burned materials, which include pyrolysis products, carbon monoxide and solid fuels (which are seen as soot and smoke). The level of this fuel-rich gas layer grows lower and lower in the room and temperature rises rapidly. The mass of combustible gases, aerosols, soot and smoke gather until one or more of the fuels reach their ignition temperature - this can be a result of radiation from the flaming fire or direct contact with the flames. The clouds of gases then catch fire at ceiling level. When the gas layer reaches an approximate critical temperature of 600°C, it generates sufficient radiant energy to bring other fuels in the room (cellulosic fuels such as floor covering and furniture) to their ignition temperatures. [3]

Hence flashover occurs, with temperatures in the room being at a maximum and the hot gas layer radiating heat from ceiling level to floor level, igniting everything in its path, including the floor. [6]

3. *Smouldering Stage*

At the commencement of this stage, the fire has consumed most of the oxygen and fuels in the room. The flames then tend to consume any available oxygen, which includes oxygen from the space under the doorway, holes in walls, holes from missing ceiling tiles and so forth. The concentration of oxygen in the air is usually 16% at this stage, with the flames of the fire almost diminished. If the concentration of oxygen falls to about 15% or lower, flames do not exist, but burning embers may remain in the room. The ceiling level temperatures are still very high and the room is full of superheated gases and smoke, some of which may be dangerous methane. There is no visibility in the room at this stage. Pyrolysis is causing the rapid deterioration of organic matter in the room and is at its highest level of the whole burning sequence. [l]

If an amount of oxygen is introduced into this superheated combustible atmosphere, a backdraft explosion will occur. However, if no oxygen is introduced the fire will eventually extinguish itself, and the contents of the room will cool down. [1]

Types Of Flashovers

There are two main types of flashovers, as described below.

1. *Radiation Induced Flashovers*

During the sequence of a room fire, the flames from burning furniture in one part of the room spread horizontally at the ceiling. A large amount of heat is radiated downwards and many materials in the room decompose. Flammable pyrolysis products (smoke) are produced and in time, individual items in the room will burst into flame. [2]

Radiation induced flashovers occur when the layer of hot gases is at ceiling level rather than at floor level, and also tend to occur more often when the radiant heat transfer travels form the ceiling to the floor, and not vice-versa. This is because as the fire burns, the gases given off contain water vapour and unburned particles (soot) , both of which are good absorbers of radiant energy. Thus, if the layer of hot gases is at floor level, it is covered by the gases which absorb radiant energy before they can reach the ceiling. [14]

2. *Ventilation Induced Flashovers*

When fires burn in conditions of limited ventilation (especially when the fire has been smouldering for a long time), flammable gaseous pyrolysis products accumulate. These do not necessarily ignite , especially if there is insufficient oxygen present. Generally, pyrolysis products are diluted with non-flammable gases such as carbon dioxide, and these can form a gummy layer on cool surfaces. Therefore ventilation induced flashovers are not frequent. [2]

Discussion

Problems With Flashover

1. *High Temperatures Involved With Flashovers*

When flashovers occur, heat is transferred down by radiation (heat transfer from one point to another by electromagnetic waves, with no intermediate material necessary). The amount of heat emitted through radiation is governed, and can be calculated using the Stefan-Boltzmann law [14]:

$$q = \sigma \varepsilon A T^4$$

Following, net energy exchange between two bodies is given by a solution of the Stefan-Boltzmann equation [14] for both of the radiating bodies, as shown below:

$$q_{net} = \sigma \varepsilon C A (T_1^4 - T_2^4)$$

Using the above equation, it has been calculated that for a fire at ceiling level in a room to flashover and cause items at floor level to ignite by radiant heat, it is necessary for the fire at ceiling level to be at 1077°C. This temperature is almost as hot as it is needed to melt copper. [14]

danger. As the fire fighters searched and ventilated the building, flashover was achieved, as an explosion caused much of the flammable material to ignite. [2]

Another example of a case where modern pyrolysis products caused flashover, occurred in a three-storey rooming house in Ohio on February 18, 1992. An overstuffed polyurethane-type chair had been ignited by an improperly discarded cigarette. The fire continued to be fueled by combustibles and wooden wall paneling, flashed over and spread to upper floors through an open staircase. Six deaths resulted. [9]

One solution which could decrease the speed of the spread of fires and allow fire fighters more time to save victims and to control the fire, is the installation of sprinklers, smoke detectors, and fire alarms connected to the fire brigade. [4] [121

3. *Flashover And Arson*

Arson is defined as 'the crime of maliciously and intentionally, or recklessly, starting a fire or causing an explosion'. [7] There are several characteristics of flashover which may suggest arson, as new evidence is beginning to show. These include false low points which suggest multiple points of ignition, and burn patterns which may suggest the pouring of liquid accelerants. Also, if flashover occurs in a fire, it may destroy useful evidence of arson.

An example of a case where an accidental flashover was mistaken for arson, was a fire which occurred in Arizona in 198 1. Fire investigators determined the fire to be a case of arson due to heat-warped metal; burn patterns on the trailer floor in the shape of pools of liquid; multiple locations where the fire appeared to start; and signs of tremendous heat. Advances in fire investigation can now explain this evidence by flashover, as discussed earlier and below. [5]

- False Low Points

False low points can be produced by flashover from radiant energy transfers. An example is seen when a ceiling filled with hot gases radiates heat downwards, onto the tops of furniture, rugs and so forth, with fires breaking out in many places. This may suggest multiple points of ignition, as is seen in cases of arson. To ensure that the fire investigator makes the correct judgement in such cases, the following characteristics of radiant heat flashovers can be used, including:

- the presence of a source point or area for radiant heat (an area which has sustained a very hot fire usually over an extended area, like a wall or a ceiling);
- the presence of several radiant heat 'low point' areas of ignition, which are positioned in 'view' of a source point or area for radiant heat; and
- evidence that these areas began burning after other parts of the building or structure had already burned. [141

Another example which consequently suggest multiple points of ignition is when the heat from a general fire melts and ignites polystyrene light diffusers used in ceiling lighting fixtures or asphalt from a collapsing roof. [3]

- Burn Patterns

Evidence shows that flashover can cause the production of burn patterns similar to those burn patterns which are caused by flammable liquids (commonly used in arson). For example, a flashover sustained for two minutes produces deep 'alligatoring' in a wooden floor. Such a pattern can easily be mistaken for burn patterns which are produced by flammable liquids. [6]

Another case shows that in flashover, radiant heat patterns take many shapes including sharp, continuous and irregular edges. These patterns depend on what is on top of the floor covering the edges of the burn pattern. Cloth materials (such as curtains, clothing, bedding) tend to produce anomalous burn patterns by protecting the material underneath , and these burn patterns can be easily mistaken for the 'obvious pour patterns' of flammable liquids in arson fires. [6] Due to the similarity in the interpretation of anomalous burn patterns on floors and pour patterns, it is very important for the fire investigator to determine whether a room or a building achieved flashover. This is done by following the simple guidelines where:

- in buildings where it is obvious that the upper portion of the room has been exposed to temperatures much higher than the lower portion of the room or the floor region; and very sharp smoke or heat lines approximately two or three feet off the floor are seen on the walls - flashover has not occurred and the fire investigator can interpret the burn patterns as flammable liquid burn patterns
- the fire investigator can determine that flashover was achieved when it is seen that the entire room was burned all the way to the floor. In this case, however, if all of the carpet has been burned off the floor and minor variations in the depth of the char can be seen on the underlying wood, the fire investigator can determine burn patterns to be flammable liquid burn patterns (especially if a positive laboratory analysis is given for flammable liquid residue). [6]

It should be noted, that if there is any doubt present in the mind of the fire investigator, laboratory analysis of fire debris samples should be used as further proof. In recent years, laboratory methods and instrumentation have greatly improved in the field of fire investigation. New methods are extremely sensitive, and therefore only require minute amounts of sample for analysis, one factor which proved to be a great obstacle in previous years. Also, standard test methods and quality control are now being used in laboratories. Laboratory analysis results can prove with certainty whether a flammable liquid was present or not.

- Destruction Of Evidence Of Arson

Arson is commonly achieved by the pouring of flammable liquids directly onto the floor area. However, if the room achieves flashover, the radiant heat produced may obliterate some of the more subtle indicators on the floor, and this, as opposed to what has been already discussed, works against the detection of arson. [3]

Thus, there are also various factors which the fire investigator can use in the detection of 'true' cases of arson (in which flammable liquids are used). One of these factors is that there may be various rooms in a building where flashover was not achieved, where obvious pour patterns are present or the rooms stink of gasoline. The evidence found in these rooms can then be used as an indicator in the investigation of other rooms in the building, where flashover was achieved. This information can, for example, assist the investigator in the identification of subtle pour patterns in rooms within the building that experienced flashover. Another of these factors is that if there is proof present that personal possessions (such as photographs, clothing) were removed from a building prior to the fire, this constitutes as proof that someone had prior knowledge of the fire - and this is a strong indicator of arson. [6]

4. *Further Training And Education*

- The Fire Investigator

There have been many cases which involve flashovers, where results of the investigation made by the fire investigators, have shown that the fire investigator lacked in updated knowledge in this particular area. The fire investigator should have a willingness to consider new evidence and findings in the field of fire investigation; a willingness to consider new things which have not been 'officially' taught to them; and a willingness to keep an open mind.

An example where this has failed, leading to incorrect judgments, is the case of the black smoke and white smoke. [6] In the 1990's, furnishings are made from different combustible materials as compared to the 1940's and the 1950's. In the 1940's and 1950's, white smoke was given off when furnishings burned. However, due to the various changes in the materials, today the smoke given off in such a situation will normally be black. There are still quite a number of fire investigators who will insist that white smoke occurs from the burning of normal combustibles and black smoke is derived from the burning of accelerants. This case shows the unwillingness of fire investigators to 'move with the times' and to keep an open mind.

It is important that the fire investigator remembers to utilise common sense in all investigations, that will assist in the piecing together of the many facts and information found in the investigation. Fire investigators should try not to get swayed by what others may suggest. For example, the suggestion of 'obvious' burn patterns when they are not so 'obvious', to suggest arson over accidental flashover. [6]

It is also critical that the fire investigator who has made an incorrect judgment, be able to admit this - so that they do not repeat the mistake in future investigations. Fire investigation, after all, is not an exact science.

Seminars about flashover are offered to fire investigators, so that they are aware of current issues in this field. However, these usually teach the fire investigator how to recognise a flammable liquid burn pattern after flashover has occurred. More education on the recognition of accidental burn patterns caused by flashover, and not by flammable liquids, is needed; so as to further clarify the differences present between arson and accidental fires. [6]

Finally, fire investigators should now be aware that fire debris samples should always be taken from the scene of a fire, for further laboratory analysis - so as to provide further confirmation of their judgment, or to disprove their judgment. In some cases, fire investigators do not see this as an essential step.

- The Police

Members of the police service have to be taught and educated in various aspects of fire that they simply cannot ask the fire investigator to make quick, ‘on the spot’ determinations of what occurred at a fire scene. The fire investigator may need to gather further information away from the fire scene. [6] If pressure is reduced on the fire investigator, incorrect determinations will also, in turn, be reduced.

Also, it should be noted that police service members should be aware that it is very difficult to perform investigations of fire scenes during the night hours. In turn, they should only request investigations of the fire investigations during daylight hours.

- Fire Fighters

Traditionally, fire fighters have been trained and educated to fight the seat of the fire. They were all aware that smoke could suffocate them, however the fact that smoke could also ignite or explode has only been considered by them in recent years. Hence, tire fighters are now being taught to primarily put out the flammable gases which the seat of tire produces, since it is the flammable gases which produce the heat and the smoke. [151 This is done in a manner where small bursts of water are sprayed at the gases, decreasing the heat produced by the fire, so that the fire fighters can manage to contain the fire as a whole. The problem of the high temperatures involved with flashover has been discussed previously.

Training about flashover is usually held as ‘container’ training, where a room or a house is represented by a container. It is now quite evident that fire fighters need to be exposed to training which involves tires in real houses and rooms - so as to decrease the number of fatalities, in cases of flashover. Together with ‘container’ training, and others, fire fighters are also taught to be aware of the concentration of smoke; any sudden temperature changes; and to cool the gases above their heads; when walking into a room or a house which is on fire, and where flashover is imminent. [15]

Other procedures which fire fighters use to combat flashover is to spray a heavy stream of water through a room where flashover has or could occur. The high pressure spray of water creates an area of low pressure behind it. Air rushes in to equalise the difference, and if the water spray is directed through a window of the room, the smoke will leave the room through the window. [15]

5. *The Question Of Whether To Ventilate Or Not*

One way in which to prevent flashover is to ventilate, where the layer of hot gases escapes before the critical temperature is reached. On the other hand, if no ventilation is present (or is limited), the fire is starved, where the progress of the fire slows to a point where flashover will no longer occur. The problem arises in making a decision between the two.

An example of a case where flashover occurred due to ventilation, is a fire in a single-family dwelling in South Carolina on November 7, 1993. A child had ignited a sofa with a lighter, the fire flashed over. The fire was then vented by broken windows due to an escaping adult and neighbours trying to rescue the occupants; the venting enhanced the fire spread and five deaths resulted. [10]

An example of a case where flashover occurred due to limited ventilation, is a fire at an elementary school in Maryland on October 24, 1994. Maintenance workers had applied a flammable liquid floor stripper to the wooden floor in the school gymnasium, when an undetermined heat source had ignited the flammable vapours which tilled the room. Few, if any, windows were open. The flashover fatally burned three workers and injured a fourth. [1l]

In the USA, the fire brigade uses positive pressure ventilation, where large fans with specially designed blades are used to force hundreds of cubic metres of air through a door to a building. The fans supply enough air and enough oxygenated air, so as to overcome the fire. The air pushes the heat, flames and smoke back as the air rushes through the room. In turn, tire fighters are able to enter an inferno and are able to work in a pocket of cool, clean air. Also, since all the products of combustion leave through the window, no backdraft will occur; temperatures are reduced so flashover will not be achieved; and a flow of fresh air is present for any victims which may be on the lower regions of the room. However, it should be noted that positive pressure ventilation does not always work and is dangerous if used incorrectly. For example, if no escape route for the gases is created, they will tend to blow back into the oncoming fire fighters. Many countries around the world do not use this method, and further education and training into flashover will see that this method is used more widely. [15]

Conclusion

The various problems associated with flashover were discussed and supported with various example cases. Further study into the area will provide solutions to these problems. Also, the combination of scientific knowledge (of fire investigators) and practical knowledge (of fire fighters), will help eliminate or lessen the degree of the problems. With the various groups working together, fire fighters will establish better techniques to combat flashover and flashover-related fires, so as to decrease the number of human fatalities and injuries, and the amount and cost of property destruction.

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APPENDIX A

Diagram of the sequence of a room fire and flashover. [3]