JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
DEPARTMENT OF PUBLIC WORKS AND TOWN AND COUNTRY PLANNING (DPT),
MINISTRY OF INTERIOR (MOI)

THE STUDY
ON
DEVELOPMENT OF A BUILDING SAFETY SYSTEM
FOCUSING ON FIRE PREVENTION
IN
THE KINGDOM OF THAILAND

FINAL REPORT

VOLUME III

TECHNICAL MANUAL FOR PLANNING OF
FIRE PREVENTION SYSTEM

FEBRUARY 2003

THE BUILDING CENTER OF JAPAN
NIPPON KOEI CO., LTD.

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VOLUME OF REPORT

VOLUME I SUMMARY

VOLUME II MAIN REPORT

VOLUME III TECHNICAL MANUAL FOR PLANNING OF FIRE PREVENTION SYSTEM

VOLUME IV APPENDIX

VOLUME III
TECHNICAL MANUAL FOR PLANNING OF FIRE PREVENTION SYSTEM

TABLE OF CONTENTS

ABBREVIATION

AUS	Australia
BLB	By-Law of Bangkok
BSL	Building Standard Law of Japan
CO	Carbon Monoxide
CO_2	Carbon Dioxide
D	Depth
DS	Duct Space
EIT	Fire Protection Standard of Engineering Institute of Thailand
EV	Elevator
FD	Fire Door
FPB	Fire-proof Building
FRA	France
FS	Fire Shutter
Hb	Hemoglobin
HCN	Cyanide Nitrogen
IBC	International Building Code of United States
ICU	Intensive Care Unit
IFC	International Building Code of United States
ISO	International Organization for Standardization
K_2CO_2	Potassium Carbonate
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MR	Ministerial Regulation
NCIF	Noncombustible Interior Finish
NFPA	National Fire Protection Association
O_2	Oxygen
PS	Pipe Shaft
UK	United Kingdom
USA, US	United States of America
WC	Water Closet

MEASUREMENT UNITS

Extent

cm^2 = Square-centimeters
m^2 = Square-meters
km^2 = Square-kilometers

Volume

cm^3 = Cubic-centimeters
m^3 = cu.m = Cubic-meters
l = Liter

Length

mm = Millimeters
cm = Centimeters (cm = 10 mm)
m = Meters (m = 100 cm)
km = Kilometers (km = 1,000 m)
inch = 2.54 centimenters

Weight

g = Grams
kg = Kilograms
ton, t = Metric tonne

Energy

kcal = Kilocalories
kJ = Kilojoule

Time

sec, s = Seconds
min = Minutes
h, hr = Hour
d = Day

Others

% = Percent
^0C = Degree Celsius
lx = Lux
ppm = Parts per million
^{0} = Degree of angle

INTRODUCTION

This *Technical Manual for Planning of the Fire Prevention System* is one of the fruits of the Study on Development of a Building Safety System focusing on Fire Prevention in the Kingdom of Thailand. The Study has been conducted by Japan International Cooperation Agency (JICA) for the period of twenty months between 2001 and 2003.

In Thailand, there has been a boom in large-scale construction projects of office buildings, hotels, and shopping centers, especially in the Bangkok Metropolitan area. Although most of these structures were built since the beginning of the 1990s, losses due to fires have become a serious problem. This reflects insufficiency of clarity in the building codes on which building control are based, as well as differences in the ways in which individual building engineers apply safety standards to their designs. In spite of the strengthening of the fire prevention system of the buildings by responsible organizations, defects on the fire prevention system has been considered still remained. Upon these circumstances, the Government of the Kingdom of Thailand requested the Government of Japan to conduct the Study.

The Study formulated the strategies for development of the fire prevention system for both buildings newly constructed and existing buildings, including recommendations on amendments of the Ministerial Regulations under the Building Control Act in terms of the fire prevention system.

In the course of the Study, the survey of the existing buildings identified improper planning of the fire prevention system, such as the fire detectors located right in front of outlets of air conditioners and the escape staircases with many changes of paths. Those defects seem due to the insufficiency of the clarity in the building codes as well as insufficient understanding of the fire prevention system.

This *Technical Manual* aims to put principles of the fire prevention system together. The fire prevention system is formed by the proper management system and the fire protection system which is physically constructed in the buildings. This *Technical Manual* is intended to focus on the fire protection system upon which the proper management secures the fire safety of the buildings.

The *Technical Manual* consists of three parts;

□ Part I Fire Protection System in General:

To present principles of the outbreak of fire and fire extinguishing. This part also provides the behavior of fire in each fire development stage and the basic requirement of the fire protection system.

□ Part II Fire Protection System in Particular:

To introduce the fire protection system individually and its planning issue.

□ Part III Fire Protection System by Classification of Building:

To point out the typical planning issue of each classification of building.

Requirements in the building codes have the nature of amending with the times to adapt to the socio-economic conditions including newly innovated technologies and transitions of the construction industry. On the other hand, the principles presented in this *Technical Manual* are the invaluable substances.

The *Technical Manual* is expected to be the introduction to the building codes and technical documents for;

□ Architects and building engineers, responsible for planning, designing, and inspection of buildings,

□ Building officials, taken in charge of the technical assessment and inspection.

Finally, this *Technical Manual* is sincerely hoped to be helpful in developing the buildings with the proper fire protection system.

PART I FIRE PROTECTION SYSTEM IN GENERAL

1 Major Fires in the Past

The Great London Fire in of 1666 is considered the event that triggered constructive actions for setting up fire codes. Firstly, a new act for reconstruction was legislated to restrict wooden frame construction and use of wooden materials on external walls in London City. Secondly, fire insurance companies were established primarily as a result of this tragedy. In order to protect their insured properties, the early fire insurance offices hired fire fighters and in 1667, formed the first real fire brigades in England.

In the early period, the main subject of the fire protection system was to prevent the conflagrations in the urbanized areas.. Therefore the fire codes were strongly related to the city planning. The fire zones and minimum width of streets were regulated in the fire codes.

In the late19th century, cities in the United States and European countries experienced a number of large fires with more than 100 deaths in theaters. Following the increase of floor area and height of buildings in the 19th and 20th centuries, the main focus of fire protection systems shifted from conflagrations to single building fires. The fire codes regulated fire resistant construction, fire extinguishing equipment, and supporting systems for fire fighting.

In 1911, a fire that broke out in the Triangle Shirtwaist Factory in New York City killed 147 people. This tragedy is typical of the type of events that induced the drawing up of rational evacuation planning. The NFPA Committee on Safety to Life issued the Building Exits Code in 1927, which is the origin of the present Life Safety Code (NFPA 101).

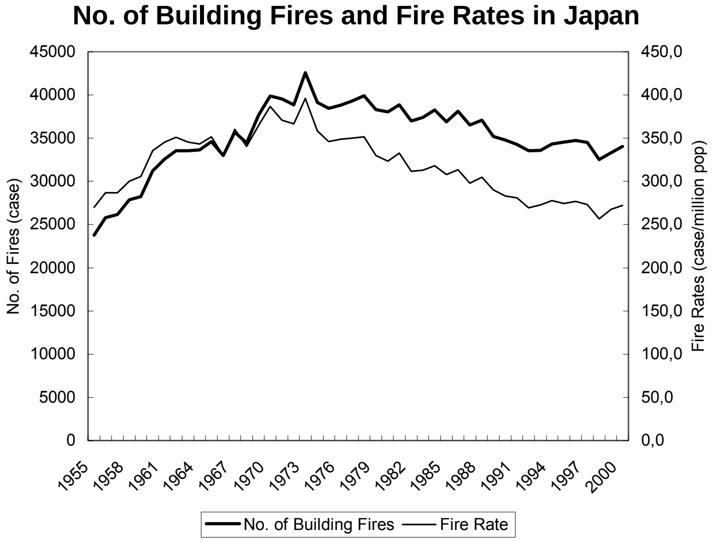
Major Fires in the Past

Type of Fire	Major Fires			Damage	
	Year	Description	Country	Buildings Burnt (building)	No of Death (death)
	1666	Conflagration in London	England	13000	6
	1689	Fire at a theater	Denmark	-	210
	1729	Conflagration in Istanbul	Turkey	12000	7000
Conflag-ration	1752	Conflagration in Moscow	Russia	18000	-
	1756	Conflagration in Istanbul	Turkey	15000	100
	1780	Conflagration in Leningrad	Russia	11000	-
	1782	Conflagration in Istanbul	Turkey	18000	-
	1791	Conflagration in Istanbul	Turkey	32000	-
↓	1795	Conflagration in Istanbul	Turkey	30000	-
	1816	Conflagration in Istanbul	Turkey	15000	-
	1836	Fire at a theater	Russia	-	700
	1841	Conflagration in Izmil	Turkey	12000	-
	1842	Conflagration in Hamburg	Germany	6219	100
	1846	Fire at a theater	Canada	-	200
Fires in theaters	1871	Conflagration in Chicago	USA	17430	300
	1876	Fire at a theater	USA	-	283
	1881	Fire at a theater	Austria	-	640
	1883	Fire at a hall	England	-	183
↓	1883	Fire at a theater	Russia	-	270
	1887	Fire at a theater	France	-	115
	1897	Fire at a bazaar	France	-	124
Fires in high-rise buildings	1903	Fire at a theater	USA	-	602
	1911	Fire at a office building	USA	-	145
	1922	Conflagration in Izmil	Turkey	-	2000
	1929	Fire at a hospital	USA	-	124
↓	1946	Fire at a hotel	USA	-	119
Fires in various buildings	1967	Fire at a department store	Belgium	-	322
	1980	Fire at a hotel	USA	-	84
	1982	Fire at a factory	Russia	-	50
	1983	Fire at a movie theater	Italy	-	64
	1993	Fire at a doll factory	Thailand	-	211

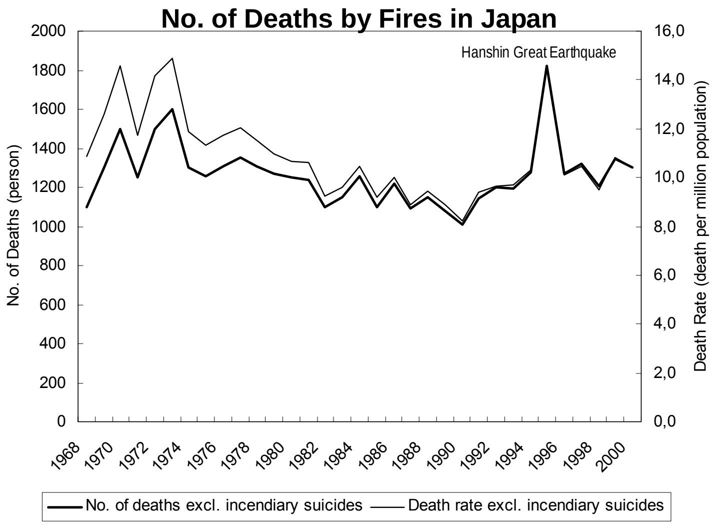
2 Fire Loss in Japan

The number of building fires and occurrence rate of fires (fire rate) have gently decreased over the past 30 years following a period of high rates during the high economic growth period of 1955 - 1970.

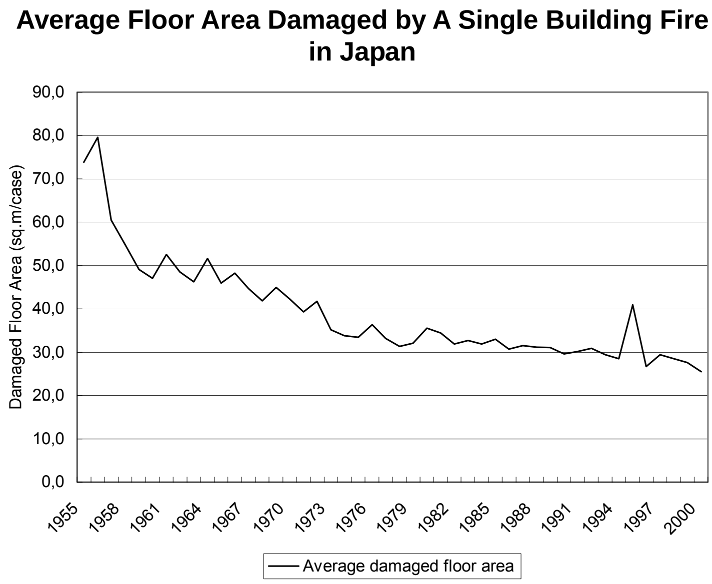
Both indexes are considered to be related to the volume of heat consumption used in buildings and to socio-economic conditions.



Similar to the trends of fire rates, the number of deaths has generally decreased since the 1970s, except in 1995 when the huge Kobe earthquake occurred in western Japan.

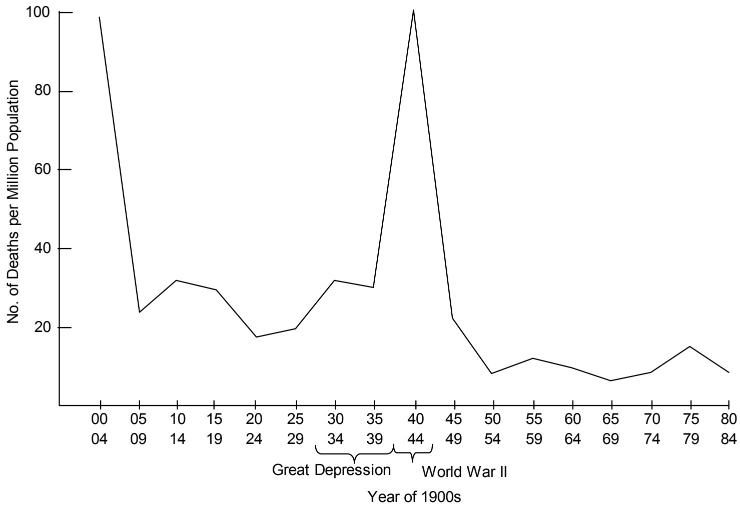


The average floor area damaged by a single building fire has steadily declined in the past fifty years, except in 1995 due to the huge earthquake and its conflagration. The reduction in damaged floor area is a result of the strengthening of public fire fighting services and improvements in fire resistant construction.



On the other hand, the record for building fires in the United States shows steady improvement throughout the twentieth century except during the Great Depression and World War II periods. The death rate per million of population has improved from around 100 deaths in the period between 1900 and 1904 to less than 20 deaths after 1950.

Death Rate of Building Fire in United States



It is the common tendency in Japan and United States that residential buildings account for the largest share in the number of fires among all building types. The number of residential fires accounts for more than half of the total fires in Japan. Its share is 56.3%, consisting of general dwellings (38.3%), multipurpose dwellings (3.7%), and apartment houses (14.3%).

In spite of the large share of residential, its average damaged floor area and loss amount per building fire are less than the averages of the other twenty-nine building categories. Public baths (191.8 m^2/case), factories (97.0 m^2/case), and warehouses (85.8 m^2/case) are the three largest categories for damaged floor area. Those classifications often have rooms with a large floor area due to characteristics of occupancy.

The three largest average loss amounts are for public baths (25.91 million JPY/case), recreation halls (12.49 million yen), and factories (10.61 million yen) because those types of buildings also have large rooms and high-price properties of equipment and goods.

Loss of Building Fire by Classification of Building in Japan in 2000

Classification of Building	No. of Fires		Damaged Floor Area		Loss Amount	
	(case)	Share (%)	(m2)	Avg of One Building Fire (m2/case)	(mil. JPY)	Average of One Building Fire (mil.JPY/case)
General dwellings	13027	38,3%	658542	50,6	52987	4,07
Multipurpose dwellings	1253	3,7%	88942	71,0	5974	4,77
Apartment houses	4874	14,3%	60697	12,5	7144	1,47
Total of Residential	19154	56,3%	808181	42,2	66105	3,45
Other Twenty-nine Classifications	14874	43,7%	782440	52,6	73800	4,96
Total	34028	100,0%	1590621	46,7	139905	4,11

3 Cause of Death in Japan

According to a white paper of fire defense service, the largest cause of death is carbon monoxide poisoning and asphyxiation which accounts for 40% of the total number of deaths in Japan. Its number can be further increased by including the burns who fail to evacuate due to obstruction of smoke and inhalation of carbon monoxide.

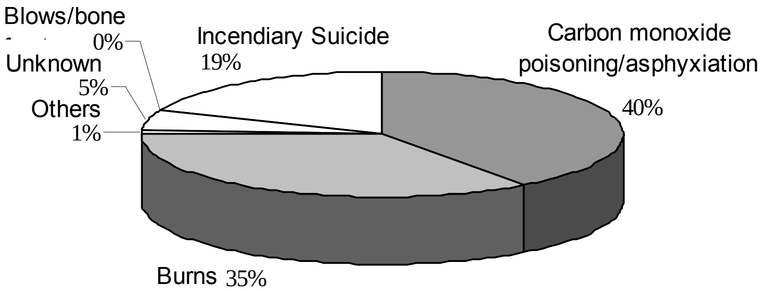
The largest sequence that leads to death is failure in evacuation that is caused by late detection, late judgement, rapid fire spread, missing opportunity, and just failed. Among these five sequences, the late detection of fire is the highest sequence.

The largest age group is people who are sixty-five years old or more, which accounts for 50% of the total number of deaths. Infants less than six years old form the next main age group with a share of 3.3%.

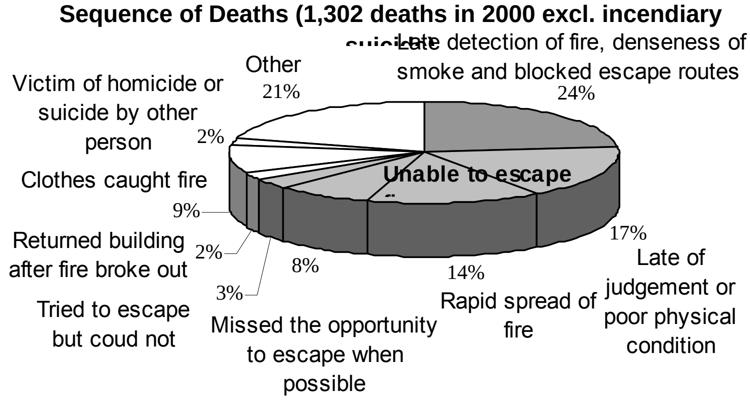
On the other hand, physical disabilities and sleeping conditions are strongly related to the number of deaths. The former consists of 201 deaths, equivalent to 15.4% of the total, while deep sleepers account for 180 deaths.

The early morning is a significant time of day in the number of deaths. Each one-hour period from one to five o'clock in the morning accounts for around 100 deaths or more.

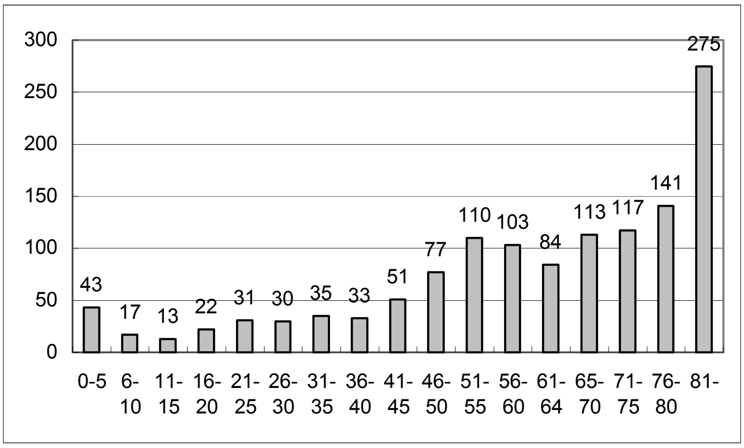
Causes of Deaths (1,368 deaths in 2000 incl. incendiary suicide)



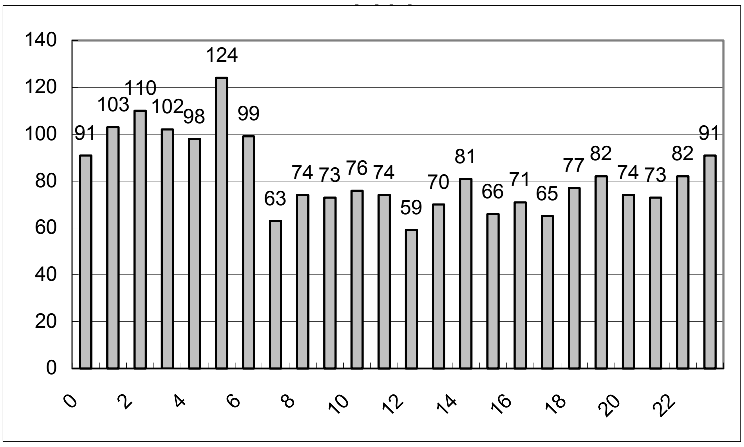
Sequence of Deaths (1,302 deaths in 2000 excl. incendiary



Number of Deaths by Age
(1,295 fatalities in 2000 excl. 7 deaths unidentified with age)



Number of Deaths by Time Zone of Outbreak of Fire
(1,978 fatalities of all kinds of fires in 2000 excl. incendiary



4 Rational Fire Safety Level

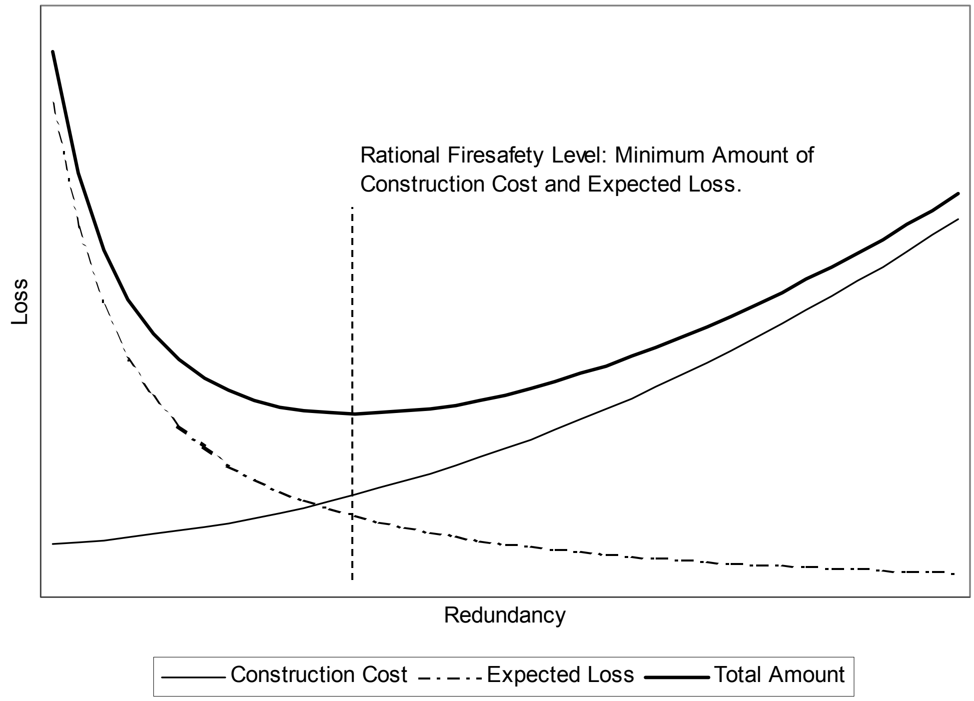
Fire protection has been continuously improved following typical fires in Japan and the United States. The improvements are seen in the reduced fire rates, death rates, and damaged floor areas, as indicated in the fire statistics.

In spite of the improvements, the most appropriate fire safety level has never been found from a technical point of view. The various elements of a building have an inherent riskness in their mode of use and construction materials. Those elements affect the fire safety level of the building. In other words, every element of a building has a consequence for fire safety. For example, the home kitchen range: if controls are placed in front, there is a greater risk of fires started by children playing; if controls are placed in back, there is a greater risk of clothing ignitions during ordinary use.

On the other hand, the ideal fire safety level is to prevent any fatalities and expected losses. However the expected losses will not become zero, even if unlimited construction cost is available for fire protection. The most rational fire prevention system is considered to be determined through the competing minimization (optimization) of construction cost and expected loss.

Therefore, fire protection systems specified in fire codes are developed from experiences and lessons of large building fires in the past. Due to lack of logical verification methods for fire safety of buildings, required fire protection systems focus on preventing large personal and property losses in a building that has a large number of occupants, while fire protection systems are moderately required for residential buildings that have rather small capital.

Rational Fire Safety Level by Construction Cost and Expected Loss



5 Principles of Fire and Fire Extinguishing

The nature of fire is a rapid and self-sustaining oxidation process with heat and light in varying intensities. In other words, fire can be defined as a phenomenon of combustion which goes out of control by mankind and damages properties and lives.

In principle, combustion is a chemical reaction in which a combustible substance is combined with oxygen to generate a large quantity of heat and light. It requires three elements to start the chemical reaction within the limit of flammability:

- □ Fuel: something to burn (fuel);
- □ Heat or thermal energy: a source of ignition; and
- □ Oxygen: necessary to maintain combustion.

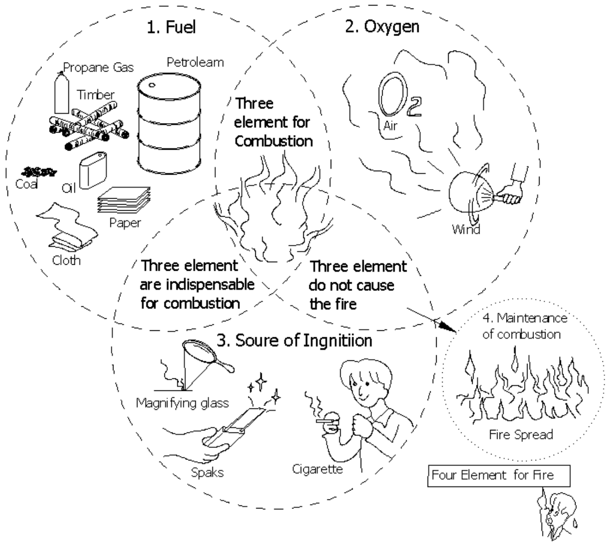
Continuous supply of those three elements is also required for the maintenance of the combustion (or chemical reaction) to become the fire.

The limit of flammability refers to the concentrations of gases at which combustion can break out:

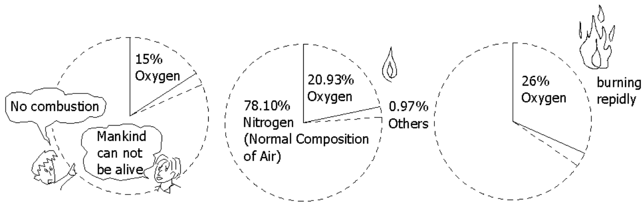
- □ 15% oxygen: failing to ignite,
- □ 26% oxygen: accelerating combustion twice as fast as 21% oxygen of the normal condition.

In the course of combustion, solid and liquid fuels are firstly vaporized to flammable gasses, which are ignited after mixing with oxygen to the limit of flammability.

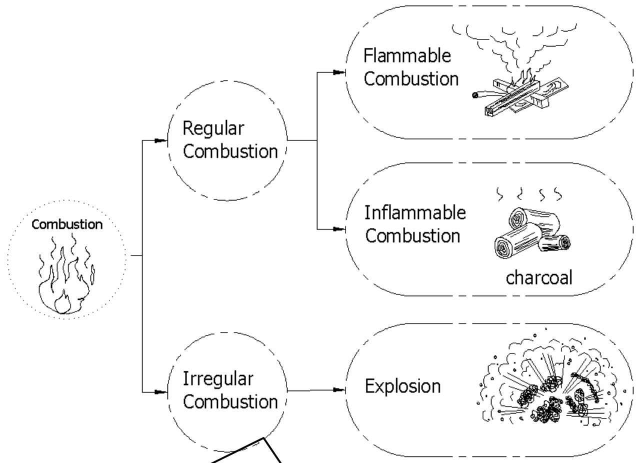
Three Elements of Combustion



Composition of Air (Limit of Flammability)



Classification of Combustion



The combustion is classified into three categories;

- Flammable combustion with flame,
- Inflammable combustion without any gaseous phase, and
- Explosion of abrupt oxidation or decomposition reaction producing the increase of temperature and/or pressure.

Fire extinguishing is principally an opposite action to remove one of the three elements of combustion. It aims to control the oxidation by:

- Removal of the fuel,
- Suffocation to prevent an oxygen supply,
- Cooling of the fuel to a temperature less than its ignition temperature, and
- Interruption of the chain reaction of the oxidation.

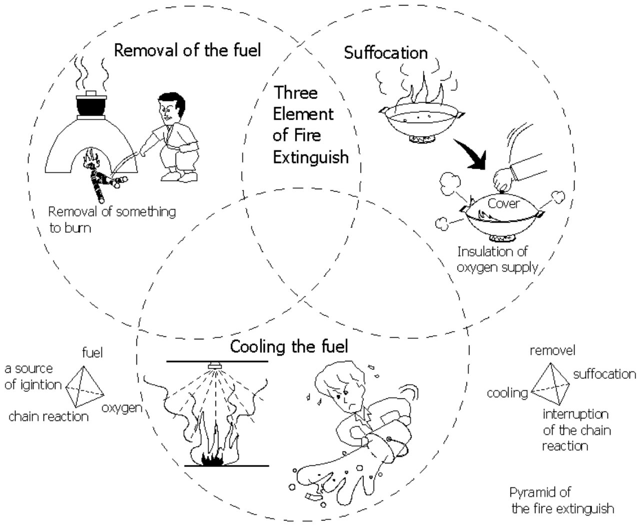
Water is the general fire extinguishing agent. The vaporization of water absorbs a large quantity of heat, amounting to 2256.3 kJ/kg of latent heat, that is much larger than other liquid substances. Water has three advantages to extinguish normal fire (class A fire):

- High efficiency to cool the fuel,
- Low price, and
- Easy availability in large quantity.

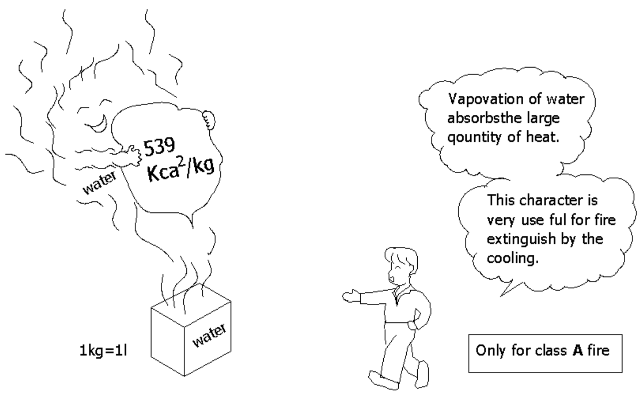
However, water does have some disadvantages for extinguishing fire:

- Electrical fires (class B fire), due to electrical conductivity of water, and
- Oil fires (class C fire), in which water can spread the fire because water is heavier than oil and diffuses the oil.

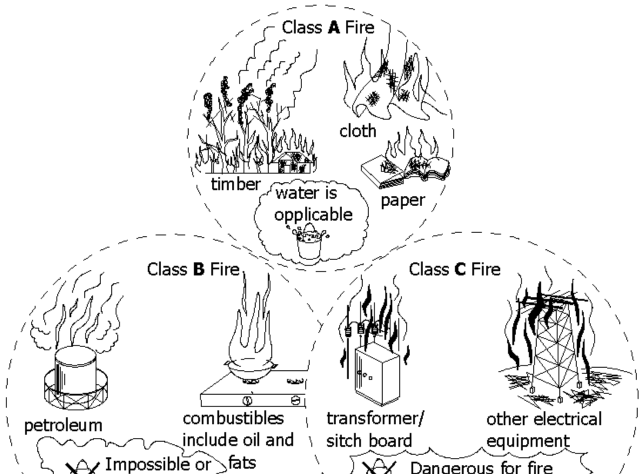
Three Elements of Fire Extinguish



Effectiveness of Fire Extinguishing by Water



Appropriate Fire Extinguishing by Type of



6 Sequences of Fire in a Room and Building

Fire spreads over the surface of the combustible materials in a room in its initial development stage. During this stage, the combustion reaction relies on the conditions in the part of the building where the fire originated.

In the development stage, the flame grows and spreads over the furniture, walls, and ceiling. The heated gases and smoke, which are stored below the ceiling, cause the rapid fire spreads along the wall surface by thermal radiation. The intense combustion breaks windows and walls making openings that supply fresh air. As a result, the fire reaches the full development stage.

In the transition from initial development to full development, the conditions of the room are drastically changed by rapid increases in temperature and gas concentration. This drastic change is defined as the flashover.

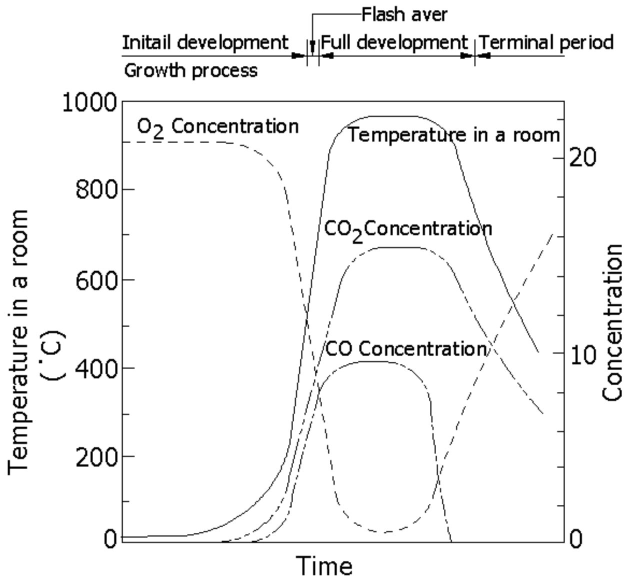
In the full development stage, the temperature and concentration of carbon monoxide (CO) and carbon dioxide (CO_2) are extremely high, while the concentration of oxygen is very low. This situation is harsh for occupants and firefighters.

After consuming all flammable gases from the combustible materials, the temperature begins to decrease. The fire completes the combustion.

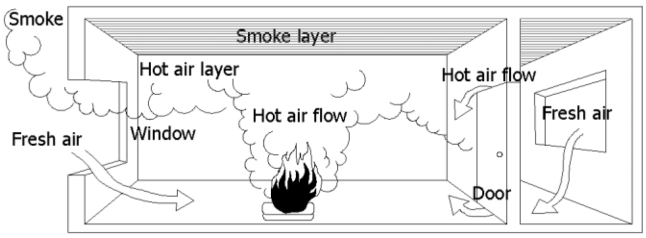
Hot smoke and heat spill out from the upper parts of openings, while fresh air enters the room through lower parts of the openings.

Full-scale experimentation shows that the temperature in a room under fire is not uniform. Temperature is higher around the ceiling and lower at the floor surface,

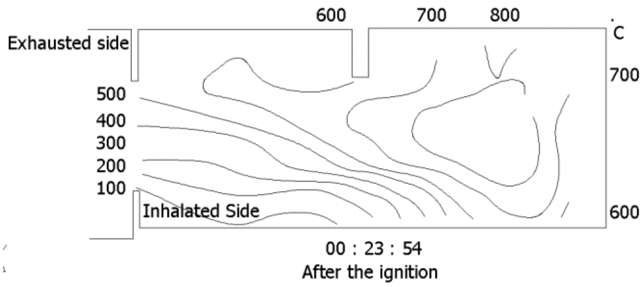
Transition of Temperature and Gasses Concentration in a Room under Fire



Sequence of Fire in a Room



Isotherm of a Room under Fire



Temperature of a room under fire is not uniformly increased.
There is a common theory that heated gasses go up to the higher part of the room, while the temperature remains low at the lower part adjacent to the inlet of air supply.

especially at the points near the intake of fresh air.

The fire in a wooden frame construction spreads upward in the early stage and then spreads horizontally. Finally the fire spreads to the downward;

(1) After the ignition of combustible materials in a room on the first floor, fire spreads to the ceiling (1).

(2) The heat spreads to the second floor through a stairway.

(3) The heat from the first floor ignites the ceiling of the second floor.

(4) The floor of the first floor is ignited, when the roof starts to burn and the fire achieves full development.

On the other hand, in a fire resistant construction, the fire grows up in a room separated from other parts of the building by fire resistant structures. If there are any openings in the room or parts with insufficient fire resistance, the fire may spread to other rooms and spaces. The typical routes of fire spread are:

(1) Openings to the outside of the building, such as windows,

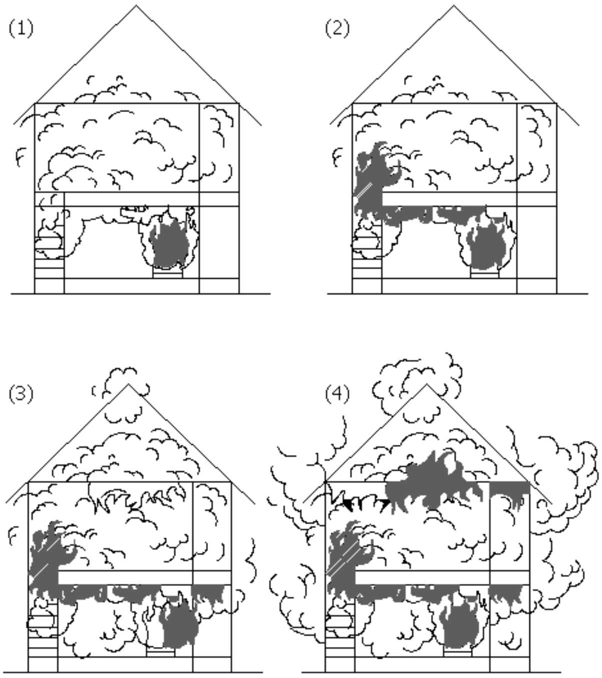
(2) Penetrated parts of the fire separation, such as pipe shafts,

(3) Openings and non-fire resistant parts connected to other rooms, and

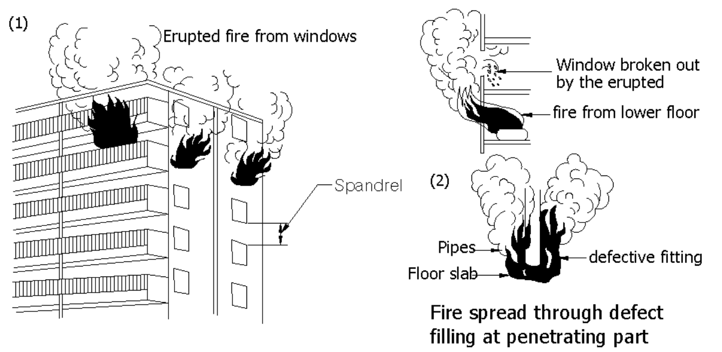
(4) Vertical openings, such as stairways, and

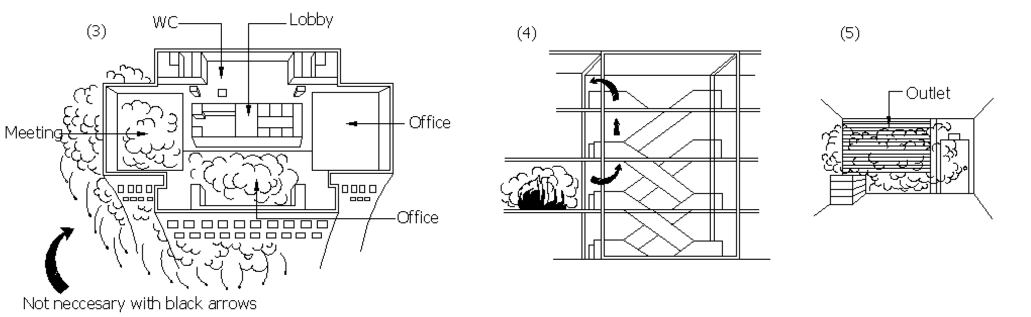
(5) Air ducts.

Sequence of Fire
in Wooden Frame Construction



Sequence of Fire
in Fire Resistance Construction





Smoke and fire spreads through opening and non-fire resistant parts to other rooms

Smoke and fire spreads through vertical shafts, i.e. stairways

Smoke and fire spreads through air ducts

7 Smoke Pollution

Combustion generates a mixture of gases and substances such as carbon, carbon dioxide, and vapor. Those gases and substances are generically named smoke. Only the soot in the smoke is visible, but combustion generates various toxic gases.

Smoke causes:

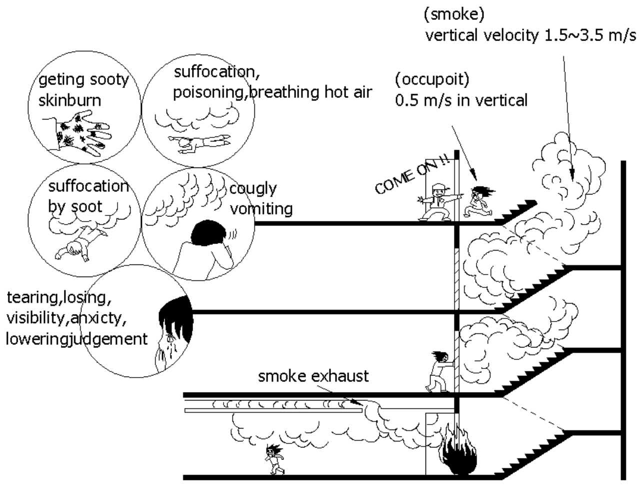
- □ Suffocation of occupants,
- □ Visible obstruction of occupants,
- □ Skin burn, and
- □ Stain and odor on the building.

Deprivation of oxygen to the brain is the major cause of death by fire. Heat and toxic gases in the smoke reduce oxygen to the brain by attacking the trachea and lungs.

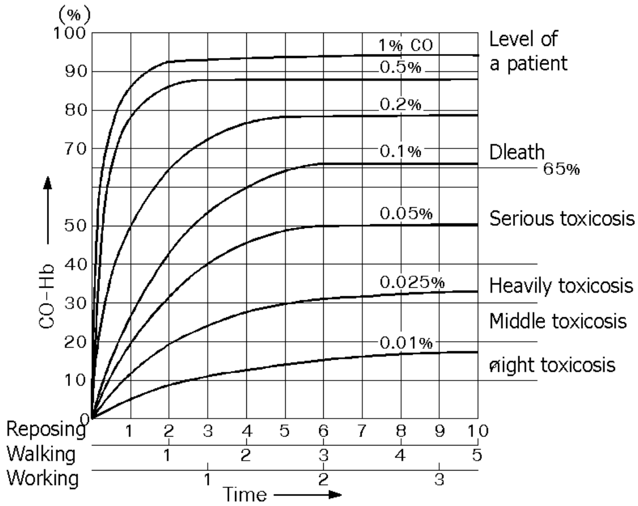
When combustion is a perfect (complete) reaction, it generates transparent and colorless carbon dioxide (CO_2). However, as an imperfect reaction, it generates soot with carbon monoxide (CO), CO_2, and other toxic gases. CO is more toxic than CO_2 and usually has the largest quantity of all toxic gases. The affinity of CO with hemoglobin is 200-220 times as strong as the affinity of oxygen with hemoglobin. An exposure of 30 minutes to 0.5% CO concentration can kill a person

Smoke has further physical characteristics that endanger life. Heated smoke rapidly rises to the higher places three or four times faster than at normal temperature. The velocity in the vertical direction reaches 1.5 - 3.5 m/s, while in the horizontal 0.5 - 0.75 m/s. For instance, smoke reaches the 4th or 5th floor within a few seconds.

Pollution by Smoke and Toxic Gases



Influence to Occupant by CO Concentration and Exposure Time



Permissible Concentration and Fatal Exposure Time

Toxic Gas	Permissible Concentration (ppm)	Exposure Time (ppm) 2 - 3 min	10 min	30 min	60 min	>60 min
CO	50					
HCN	10	270	180	135		
HCl	5	2000	500			
CH_2	0,1		150			10
NO_2	3	250		100	150	
HCHO	1					
CO_2	0,5%	30%				
NH_2	50					5000-10000
H_2S	10	700		400-700		
SO_2	5	2000				

8 Human Behavior in a Fire

How a person reacts during a fire is related to:

- □ Role assumed, previous experience, education, and personality,
- □ Perceived threat of the fire situation,
- □ Physical characteristics and means of evacuation available within the structure, and
- □ Actions of others who are sharing the experience.

The situation is complicated by the individual's perception of ambiguous fire cues, which is influenced primarily by the person's relevant training and previous fire experience, if any.

Despite the highly stressful environment in building fires, people generally respond to emergencies, often in a rational altruistic manner insofar as is possible within the constraints imposed on their knowledge, perceptions, and actions by the effects of the fire. In short, instinctive panic type reactions are not the norm.

Action and mental change is a complicated progress that adjusts with the situation. This progress is similar in the normal and emergency situation. After the awareness of a fire, occupants recognize the situation and take actions to reduce the threat from the fire by:

- □ Taking positive steps to remove the threat, i.e., initial fire extinguishing and reporting the fire to a fire department,
- □ Improving resistance to the threats, i.e., prevention of smoke invasion,
- □ Evacuation from the threats, i.e., evacuation to the outside, and
- □ Acceptance of the threats, i.e., waiting for rescue with faith.

Human behavior in a fire is often assumed to be instinctive panic. However, the danger of this reaction is classified into four different models, which are rationally understandable and possible to be solved:

- □ Danger: Unawareness of the hazards of fires.

  Solution: Education to perceive the implications of fires.

- □ Danger: Unable to take any effective reaction, while occupants recognize an outbreak of fire, i.e. customers in commercial facilities left behind the staffs in an enclosed room.

  Solution: Providing redundant fire protection systems.

- □ Danger: Panic by groups caused by occupants who individually take correct reaction, i.e. rushing to exits.

  Solution: Providing good guidance and sufficient capacity of facilities.

- □ Danger: Untimely reaction to situation in response to changes of the fire with time. The correct reaction to a situation may change from minute to minute.

  Solution: Providing the latest information by the communication system.

9 Major Planning Issues of Fire Protection Systems in Buildings

9.1 Characteristics of Buildings and Elements of Fire Protection Systems

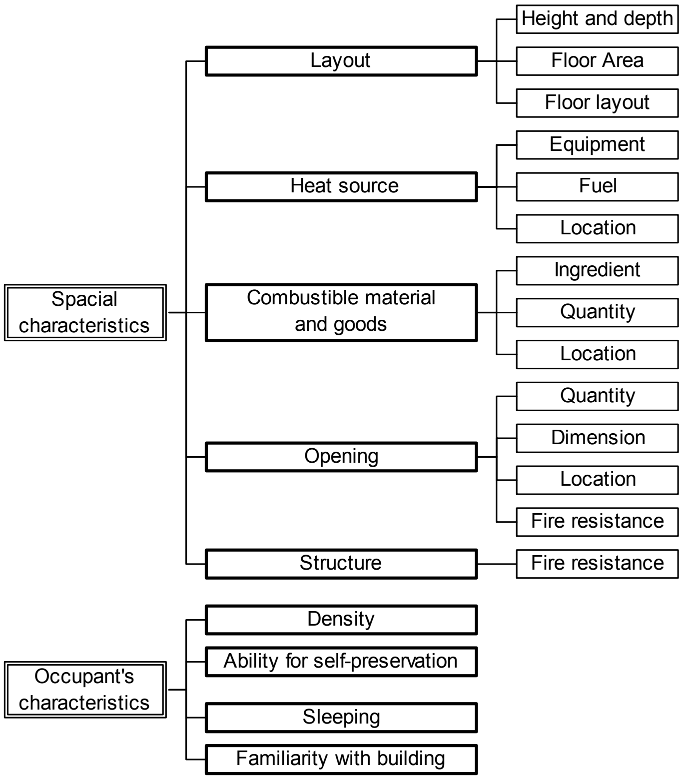
When an architect and building engineer plan a fire protection system for a building, they should firstly identify the fundamental requirements of the fire protection system.

Every building has its own unique characteristics. This diversity is the inherent characteristics of buildings that is different to industrial products. From the point of view of fire protection, the characteristics of buildings are classified into:

- □ Spatial characteristics, and
- □ Occupant characteristics.

Every planning issue of a building relates to fire safety of the building. The most important issue for the fire protection system is to suppress the fire spread for minimizing the property and personnel losses within the permissible level. In addition to the prevention of the fire spread, the planning issues include to;

Characteristics of Building



- □ Control the smoke generation and smoke spread from fire,
- □ Secure the safety evacuation of occupants, and
- □ Secure the structural stability.

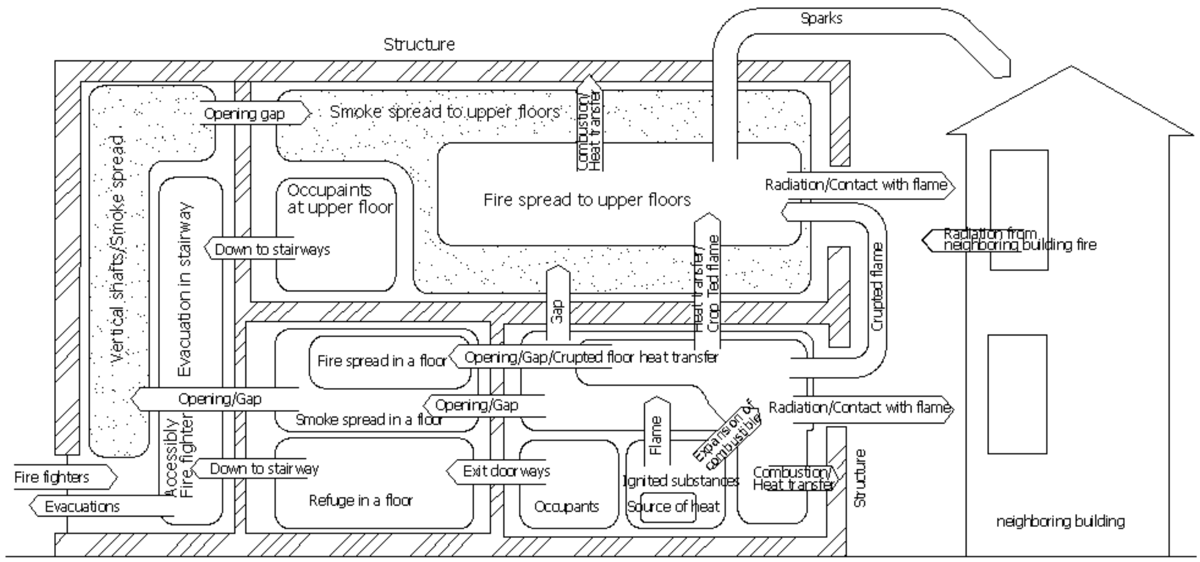
In order to cover those issues, various elements need to be taken into account as shown in the figure on the next page. However, the elements for a particular building are determined from its type of building use, floor area, height, and required safety level.

The fire protection systems for buildings can be classified into two kinds:

- □ Passive systems: physical fire protection system without any supply of electric or hydraulic power, such as fire resistant structures, noncombustible interior finish, and escape stairways.
- □ Active system: physical fire protection system with supply of electric or hydraulic power, such as a fire alarm system, automatic sprinkler system, and indoor fire hydrants.

Careful coordination between the passive and active systems produces the proper fire protection system. The passive elements have the advantage of reliability, while the active system is most effective only under proper operation, and it may be prone to malfunction by accidents. Therefore it is fundamental that the passive system secures the minimum fire safety level upon which the active system is set up to strengthen fire safety. For instance, the fire resistance wall of a passive system tightly contains smoke within a compartment, where the smoke exhaust system of the active system efficiently discharges smoke to the outside of a building.

Elements to be planned in Fire Protection System



9.2 Prevention of Fire Spread

The prevention of fire spread aims to protect:

- □ Properties,
- □ Third parties' rights and profits,
- □ Fire fighting.

Fire spread increases the generation of smoke, hazard level, and the rate of fire development. Therefore, the prevention of fire spread inevitably also relates to the protection of lives.

1) Prevention of fire development in a room under fire

Most building fires start because of the improper use of heat sources. In the initial development stage, combustible goods in a room lead the fire to its full development. However the fire protection system of the building is not able to prevent the outbreak of fire. The prevention of outbreak of fire is merely secured by proper management rather than by structures and equipment.

In the initial development, a noncombustible interior finish is able to retard the fire development after its outbreak. In other words, noncombustible materials cannot prevent the outbreak itself if a lot of combustible goods are stocked in the room. Installment of an initial fire extinguishing system is the most effective way to prevent the initial fire development.

In conclusion, the fire extinguishing system is indispensable for the room where fire must be prevented in the stage between outbreak and initial development.

2) Prevention of fire spread on the floor under fire

Main routes of the fire spread to other rooms are;

- □ Openings, such as doors and windows,
- □ Through gaps and cracks in fire walls and closed doors caused by heat. If the thermal conductivity of those facilities is inappropriate, the fire may ignite combustible goods in the adjacent rooms, due to extended exposure to high heat.
- □ Penetrated parts of fire separation, such as air ducts and pipes,
- □ Openings in external walls that allow the fire to erupt and break into adjacent rooms. If a window of the room under fire is located very close to windows of other rooms, radiant heat through the window can ignite combustible goods in the other rooms.

Therefore, fire protection at those fire spread routes is fundamental to prevent fire spread.

3) Prevention of fire spread to other floors

The main routes of the fire spread to other floors are;

- Floor slabs with high thermal conductivity and gaps in floor slabs caused by heat. Due to the buoyancy of flame and the updraft of heat, the floor slab of the upper floor is more hazardous than that of the lower floor.
- Vertical shafts that penetrate through more than one floor. Sparks and flame spread to other floors through large shafts, such as atriums, while smoke rises up through the chimney of pipe shafts, stairways, and elevator shafts.

Fire spread to other floors is prevented by ensuring that those routes are not available by the use of fire-resistant structures and fire protection equipment.

4) Prevention of fire spread to adjacent buildings

Fully developed fire may spread to an adjacent building by:

- Flames erupted from the building under fire that ignites external walls and eaves and breaks windows of the adjacent buildings.
- Radiant heat through windows and of erupted flame that ignite external walls and combustible materials in the adjacent buildings, and
- Sparks on the roof and through open (or broken) windows of the adjacent buildings.

The protection of the adjacent building from exposure to fire is to build up the fire protection system to eliminate those routes.

9.3 Prevention of Smoke Generation and Smoke Spread

Fire generates heated gases and products of incomplete combustion. Those substances are generically named smoke. Smoke has a major effect on the safety of occupants and fire fighting activities. Hazardous characteristics of smoke are:

- □ High heat that may be fatal to humans,
- □ High toxicity to humans,
- □ Spreads more rapidly and more widely than flame.

Smoke is also harmful to high-grade information systems and high-priced properties of buildings.

Smoke control is required to secure safety in:

- □ Entire evacuation routes until the completion of evacuation,
- □ Bases of fire fighting and access routes to the bases until the completion of fire extinguishing and rescue.

1) Prevention of smoke descent in a room under fire

Smoke generated by fire goes up to higher place in the room where it is trapped and forms a smoke layer. As the thickness of the smoke layer increases, the base of the layer becomes progressively lower. The object of smoke control in a room under fire is to secure evacuation to its completion before the smoke can descend to a hazardous level. Typical protection systems include:

- □ Sufficient exits in the quantity and width for evacuation,
- □ Smoke control systems, especially for large rooms with a large number of occupants. Large rooms are difficult to evacuate quickly and extinguish the fire, while small rooms with a small number of occupants may be easy to evacuate and extinguish the fire.

2) Prevention of smoke spread on a floor under fire

Smoke discharged from a room under fire spreads to other rooms through corridors and aisles.

In principle, evacuation planning must be designed to complete evacuation of the floor on which there is a fire before the smoke descends to a hazardous level. However, the occupants are often late to become aware of the fire. They may be asleep and/or disabled to evacuate by themselves. Therefore, the evacuation planning should take into account the time required to notify the outbreak of the fire to the occupants of the floor. On the other hand, the width of the corridor and aisle is often limited to enlarge the habitable floor area of the building. When the smoke rapidly spreads in the corridor and aisle, it greatly obstructs the evacuation and fire fighting.

Typical smoke control system of the corridor and aisle is to:

- □ Vent smoke out from the corridor and aisle by an exhaust system,
- □ Prevent smoke discharge by confining smoke within the room under fire.

The confining method can secure higher safety than the exhaust method. With proper design and construction, the confining method controls smoke in the corridor by integration of the pressurization of the corridor and exhaust from the rooms. The most appropriate type of smoke control system should be selected by architects and building engineers based on the specific conditions of the building.

3) Prevention of smoke spread to other floors

In high-rise buildings, smoke frequently gets to other floors through vertical openings such as stairways, elevator shafts, pipe shafts, atriums and halls.

The smoke control at the vertical openings is to prevent:

- □ Smoke spread into the vertical openings: preferable for the routes of evacuation and fire fighting, such as escape staircases,
- □ Smoke spread through the vertical openings: preferable for spaces that have the possibility of fire breaking out, such as atriums and halls.

Typical method of the former system is to:

- □ Install exhaust or pressurized system in vestibules and elevator lobbies,
- □ Enclose the vertical openings and install exhaust or pressurized system.

Appropriate method should be decided upon the spatial conditions and occupancy of the building.

9.4 Safe Evacuation

Evacuation safety is strongly related to smoke spread. The first principle of achieving a safe evacuation is to complete the evacuation before smoke reaches the hazardous level. The other typical requirements for evacuation planning are to prevent occupants from falling into panic, losing evacuation routes, and being injured by falling down.

The required time for evacuation is decided by conditions of;

- Occupants: number of occupants, density, sleeping conditions, familiarity with the building, and mental-physical ability,
- Evacuation routes: length of path, capacity (or width), intensity of illumination, and means of evacuation.

In evacuation planning, the condition of occupants determines the requirements for the evacuation routes. The evacuation routes should be formed to secure safety from any point of the building to the point of termination of the evacuation route.

When the building has spaces that are used by occupants unable to undertake self-preservation, such as infants, patients, and the handicapped, special treatment should be involved to secure higher redundancy with easy travelling routes and temporary safety areas.

9.5 Structural Stability

principle structure of a building is required to resist loads and external forces. In and during fire, heat reduces the stability of the structure. When partial or remarkable destruction is caused by the fire, it often causes the building to collapse.

The structural stability aims to:

- □ Secure life safety of occupants and firefighters,
- □ Enable the re-use of the building,
- □ Prevent damages to adjacent sites and buildings, and
- □ Preserve real assets.

Every type of construction has a unique mechanism of structural destruction by fire:

- □ In wooden frame construction, fire damages the wooden frames from their surfaces by carbonization. As the carbonized part increases, it reduces the effective dimensions of the frame. Finally, the effective dimension becomes inadequate to support the load and external forces of the building.
- □ In concrete construction, the dynamic characteristics are decreased by heat. The steel frame and reinforcement bars are particularly damaged by heat.

In principle, the structural stability is to keep the reduction of the effective dimension within the permissible level by:

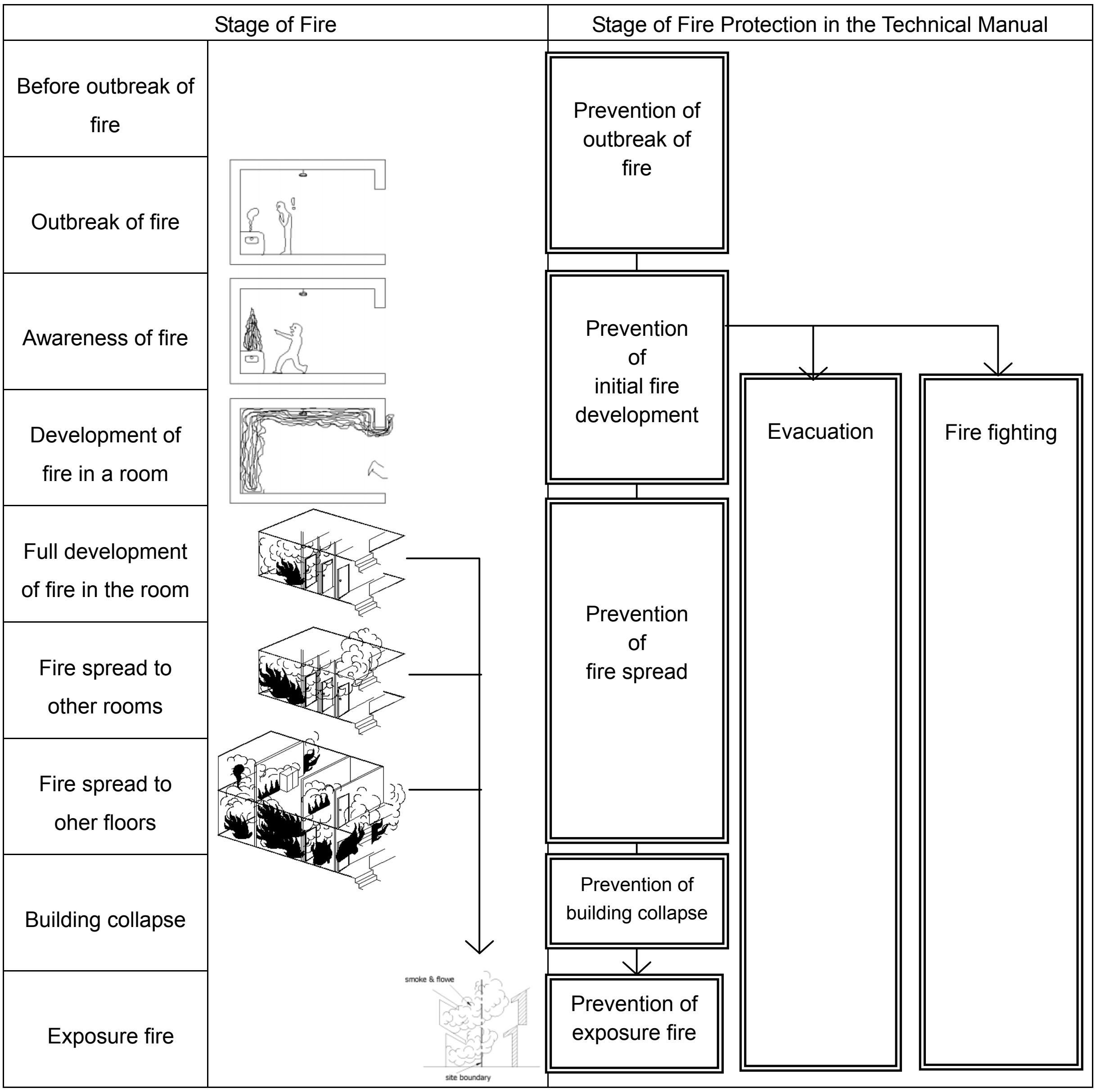
- □ Suppressing combustion and temperature increase,
- □ Providing sufficient dimensions against fire load in the room or building.

10 Fire Protection System by Stage of Fire

When fire breaks out in a part of a building, it grows to cover the whole room or compartment. In the initial development or full development stage, the fire may spread to other rooms or compartments. It may spread to other floors and to the whole building. As time goes by, the fire always changes to another stage. The fire protection planning should take into account the way fires develop and change to set up suitable fire protection systems for each stage. Proper planning is developed by giving prioritizing the stages and clarifying the purposes and functions of each fire protection system.

In practice, evacuation and fire fighting occur continuously once the fire is discovered. In this technical manual, the stages of fire are, for convenience, classified into six stages, consisting of i) outbreak of the fire, ii) initial development of the fire (from the awareness of fire to full development), iii) fire spread, iv) evacuation, v) fire fighting, vi) building collapse, vii) exposure fire.

Stages of Fire and Fire Protection System



PART II FIRE PROTECTION SYSTEM IN PARTICULARS

1 PREVENTION OF OUTBREAK OF FIRE

Principle for Prevention of Outbreak of Fire

Typical points for preventing the outbreak of fire are to control heat sources and combustible materials. Combustible material includes combustible goods and combustible interior finish material in a building. The proper control of heat sources, such as cooking, heating, and electrical equipment, is a first step in fire prevention. The planning of a fire prevention system should include the management of heat sources and combustible materials.

Every room has its own combination of heat sources, combustible goods, interior finish, occupants, and management. For example, restaurants and dining halls have cooking equipment that uses fire. In these cases, special treatment to prevent combustible materials from ignition is fundamental for fire prevention. Noncombustible goods and noncombustible interior finish materials are necessary to prevent the outbreak of fire. On the other hand, rooms with no fire producing equipment often rely on the management system rather than the physical fire protection system.

The prevention of fire outbreak is to:

- Take care of heat sources, such as flammable gases and fuels,
- Control combustible goods in rooms such as sales and storage areas where a lot of combustible materials are located,
- Select proper interior finish materials in rooms with fire equipment and without windows,
- Draw up the floor plan without any blind points, such as dead-ends behind corners,
- Supervise the fire protection system and spaces where fire may break out.

The specific fire protection system should be selected to meet the conditions of the room and building.

Care of Heat Source

Typical points for the controlling heat sources is to:

□ Select the proper type of fire equipment and fuel,

□ Set up proper conditions for incidental equipment of the selected fire equipment.

Fuel types include electricity, gas, and liquid fuels. When gas-burning equipment is selected, the fire protection system should prevent the outbreak of fire by providing protection from thermal radiation and by explosion from leaked gas. Protection should also cover the hazards at the ventilator and ventilation system.

For example;

□ When open fire is not mandatory, electricity is a preferable heat source. Boiling systems are often suited to electrical heating. Central heating is also preferable rather than individual heat source from the aspect of the fire safety.

□ When gas equipment is installed in a room, the fire protection system should:

i) Strengthen early discovery of gas leakage and indication system,

ii) Protect the gas burning equipment from flame loss by wind from openings and the ventilation system to prevent the release and build up of gas,

iii) Prevent gas leakage by installing an automatic closing system.

□ When a fuel tank is located in a building, the fire equipment should be kept at a safe distance from the tank.

Control of Combustible Interior Finish Material and Combustible Goods

1) Control of combustible interior finish material

The selection of interior finish material aims to prevent:

□ Outbreak of fire by ignition of interior finish material: thermal radiation and open fire may ignite the combustible interior finish material.

□ Fire spread by the interior finish material: fire may grow and spread by the combustible interior finish material.

Noncombustible interior finish materials are preferable for a room;

□ Having fire equipment,

□ Having large amount of combustible goods,

□ Used by a large number and various kinds of occupants.

2) Control of combustible goods

Combustible goods should be located in the safest parts of a room or building. Furniture beside a wall will easily accelerate the development of fire.

Combustible goods account for 81% of the materials that become ignited in building fires while furniture and components of the building amount to only 19%. Combustible goods should be properly managed by;

□ Removal and management of the combustible goods: Warehouse and storage rooms housing combustible goods should be planned to have proper capacity and location. Combustible goods should not be stored in escape stairways or the lobbies of elevators for firefighters.

□ Use of noncombustible products: if the location of furniture, such as lockers and closets, is determined in the design stage, the use of noncombustible material is preferable for the furniture. Selection of materials is also important for sofas, carpets, and curtains.

□ Reduction of hazards of fire spread: when rooms such as sales areas will house a large amount of combustible materials, the hazards of fire spread should be reduced by subdividing the room into smaller areas and installing an automatic sprinkler system.

Supervision of Fire Protection System and Heat Source

Daily supervision by the fire protection manager will minimize the possibility of the outbreak of fire. No physical fire protection system can eliminate the possibility of a fire outbreak, but the effectiveness of the fire protection system can be secured by proper maintenance. Negligence of daily supervision undoubtedly allows fire to break out and cause large losses.

Main objectives of the daily supervision are;

□ Control and management of heat sources and combustible materials,

□ Education and training of occupants,

□ Maintenance of fire protection system.

The highest cause of fire origins in Japan has been carelessness with cigarettes. Special care in the daily supervision is necessary to:

□ Prevent throwing cigarettes in any part of a building,

□ Restrict smoking in blind spots,

□ Designate smoking areas.

Types of Hazardous Materials

Storage of hazardous materials in quantities more than the permissible level should be managed by:

□ Handling and supervision by a hazardous materials engineer, and

□ Storing in a proper room or compartment.

Requirements of the room and compartment depend on type and quantity of the hazardous materials. The requirements generally include;

□ Fire resistant construction,

□ Noncombustible roof,

□ Fire protection equipment at windows and entrances,

□ Non-permeable structure with slope and storing measure,

□ Illumination and ventilation system,

□ Anti-lightning equipment,

□ Signboard.

Hazardous materials are classified into five types in Japan;

Type 1 Oxidized solid: solid substances that contain large amount of oxygen that can be easily decomposed by heat and cause hard combustion.

Type 2 Combustible solid: ignitable solid substances that ignite easily and have a high burning rate.

Type 3 Air reactive and water reactive chemicals: substances that can spontaneously ignite by exposure or substances that generate flammable gases or are ignited by contact with water.

Type 4 Flammable liquid: liquid substances that generate flammable vapor.

Type 5 Self-reactive material: substances that easily cause self-reaction by heating. The burning rate is high and may easily explode as a result of shock.

Type 6: Oxidized liquid: liquid substances that are strong oxidizers and can ignite combustible materials upon contact.

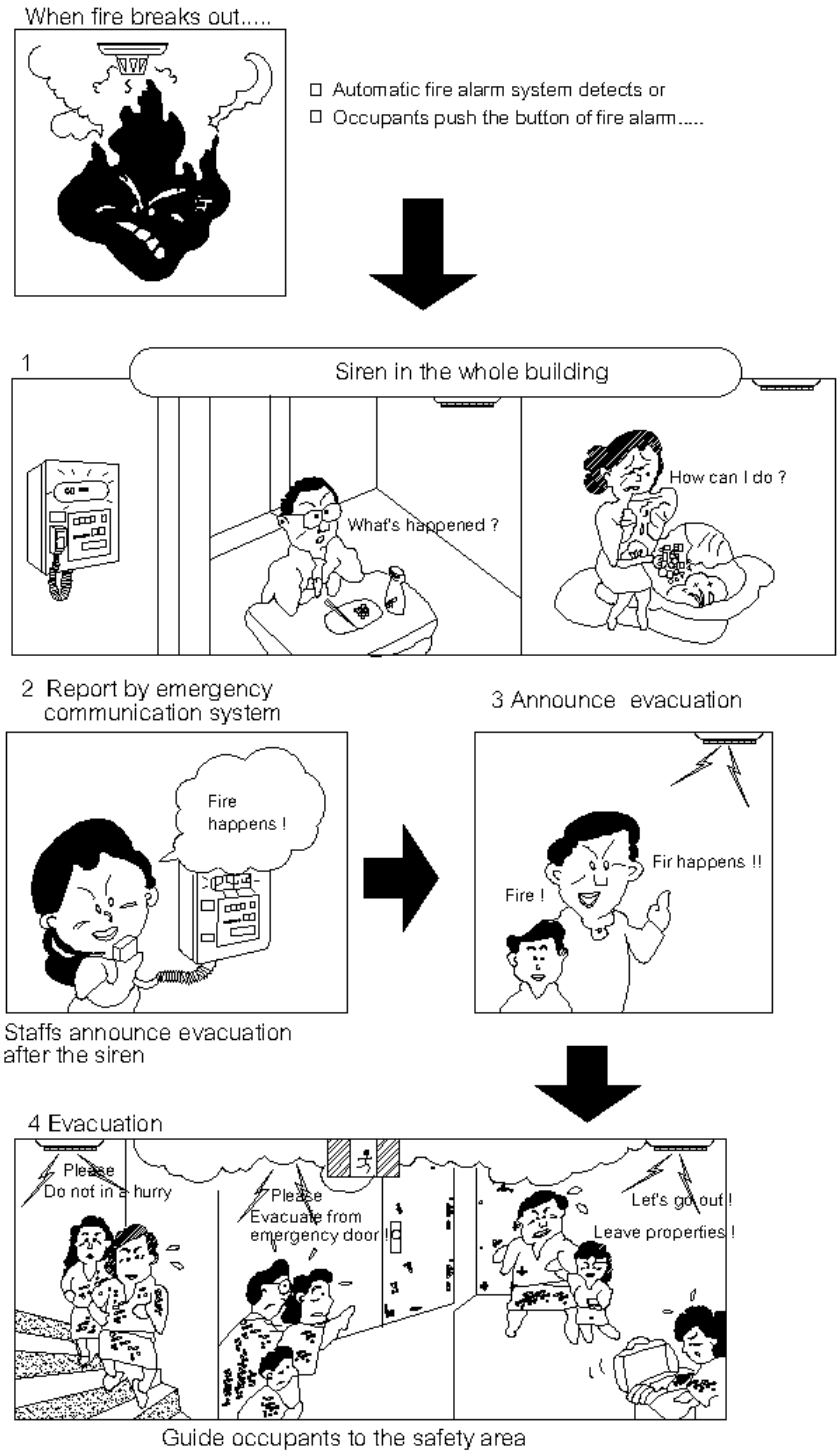
2 PREVENTION OF INITIAL FIRE DEVELOPMENT

Sequence of Detection, Alarm, and Reporting (1/2)

Every action against fire starts with the awareness of the fire.

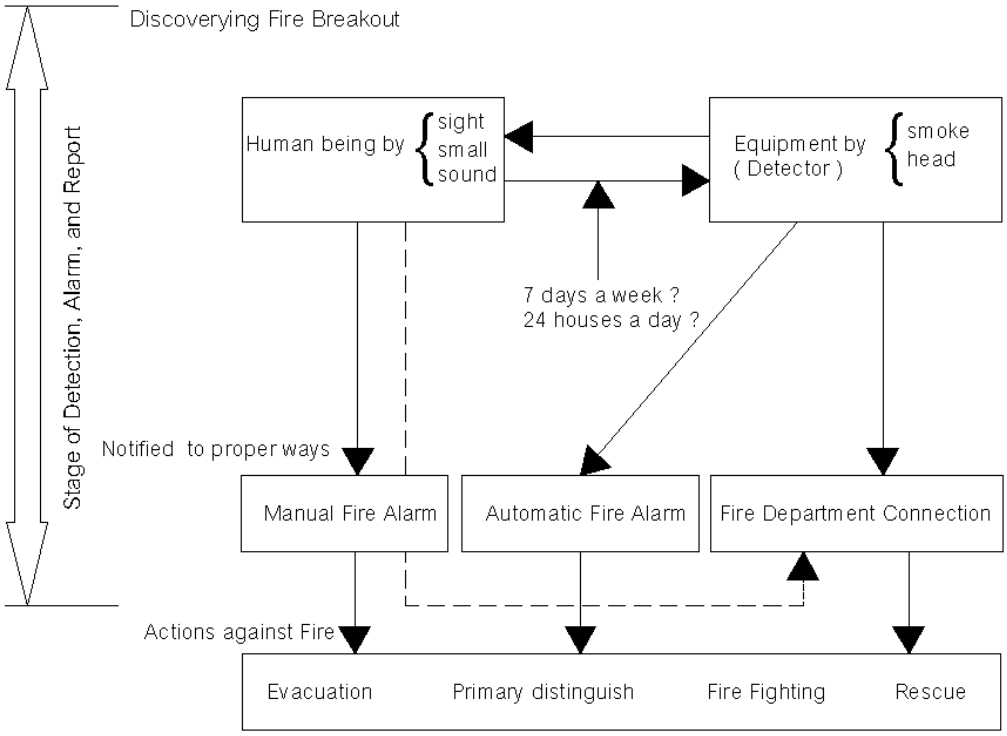
It is important to find the outbreak of the fire and notify occupants as quickly as possible. The sooner that fire is found, the more that losses can be prevented.

Sequence of Detection, Alarm, and Reporting



Sequence of Detection, Alarm, and Reporting (2/2)

Subject of Detection, Alarm, and Reporting



1)Supervising the outbreak of fire

To discover the location of the fire, the simplest way is to watch, smell, or listen for the fire expansion. However, it is unrealistic for all modern buildings to hire security guards to supervise directly all places at all times. Therefore, detectors are set in necessary areas to supervise at all times and send signals when fire is detected.

2)Notification procedures

Once a fire is recognized by somebody, he or she would shout to tell the others. But most of the time, this is not enough. Alarm systems are needed to inform all connected places.

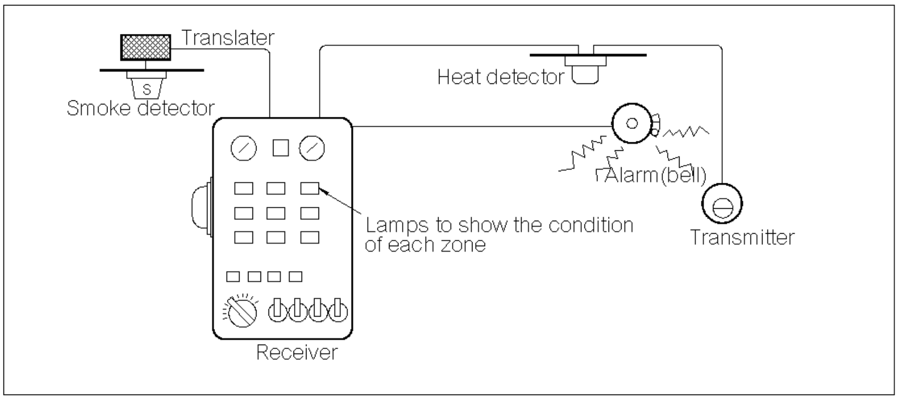
3)Practice in USA and Japan

Ideas about automatic or manual operation differ between countries. International Building Code (USA) prefers manual alarms while the Fire Service Law (Japan) adopts automatic fire alarms as its basis. On the other hand, both widely acknowledge certain exceptional cases when automatic extinguishers can take the place of alarm.

Automatic Fire Alarm System

The automatic fire alarm system is a combined system of detectors, receivers, and alarms. Since the automatic fire alarm plays an important role in dealing with the primary stage of fire, the importance of the automatic fire alarm system has been taken seriously.

Diagram of Automatic Fire Alarm System



The type of detectors used must be suitable for the conditions at the point where the detectors are installed. The detector has three types consisting of heat, fire, and smoke types. These three types are further classified into detailed types;

- □ Rate-of-rise type: monitor the rate of temperature increase.
- □ Fixed temperature type: monitor temperature.
- □ Monitoring the outbreak of fire: supervising a limited part of a room
- □ Ionization type: combination of rate-of-rise and fixed temperature types.
- □ Optical type: monitor luminous flux dispersion in a dark box
- □ Projected beam type: detect the reduction of light by smoke.

Installed Point and Appropriate Type of Detector in Japan

Installed Point		Type of Detector		
	Example	Heat	Fire	Smoke
Dusty	Lumbering factory, Painting factory	OK	OK	
Vaporish	Boiler room	(OK)		
Corrosive gasses	Battery room	(OK)		
Smoke in daily use	Kitchen	(OK)		
Very high temperature	Dry room, boiler room	(OK)		
Exhausted gasses	Parking, generation room	(OK)	OK	
Inflow of smoke	Service room, room next to kitchen	OK		
Condensation	Warehouse	(OK)		
Exposed flame	Glass factory, kitchen	(OK)		
Insufficient ventilation and storing smoke by cigarette	Conference room, restaurant, meeting room	(OK)		(OK)
Sleeping facility	Guestroom, napping room			OK
Minute particles except smoke	Corridor, aisle		OK	OK
Windy	Lobby	(OK)	OK	(OK)
Long distance from oring of smoke	Staircase, elevator shaft			(OK)
Inflammable combustion	Computer room, machine control room			(OK)
Diffused heat and smoke in a room with high ceiling and large area	Gymnasium, factory, warehouse		OK	(OK)

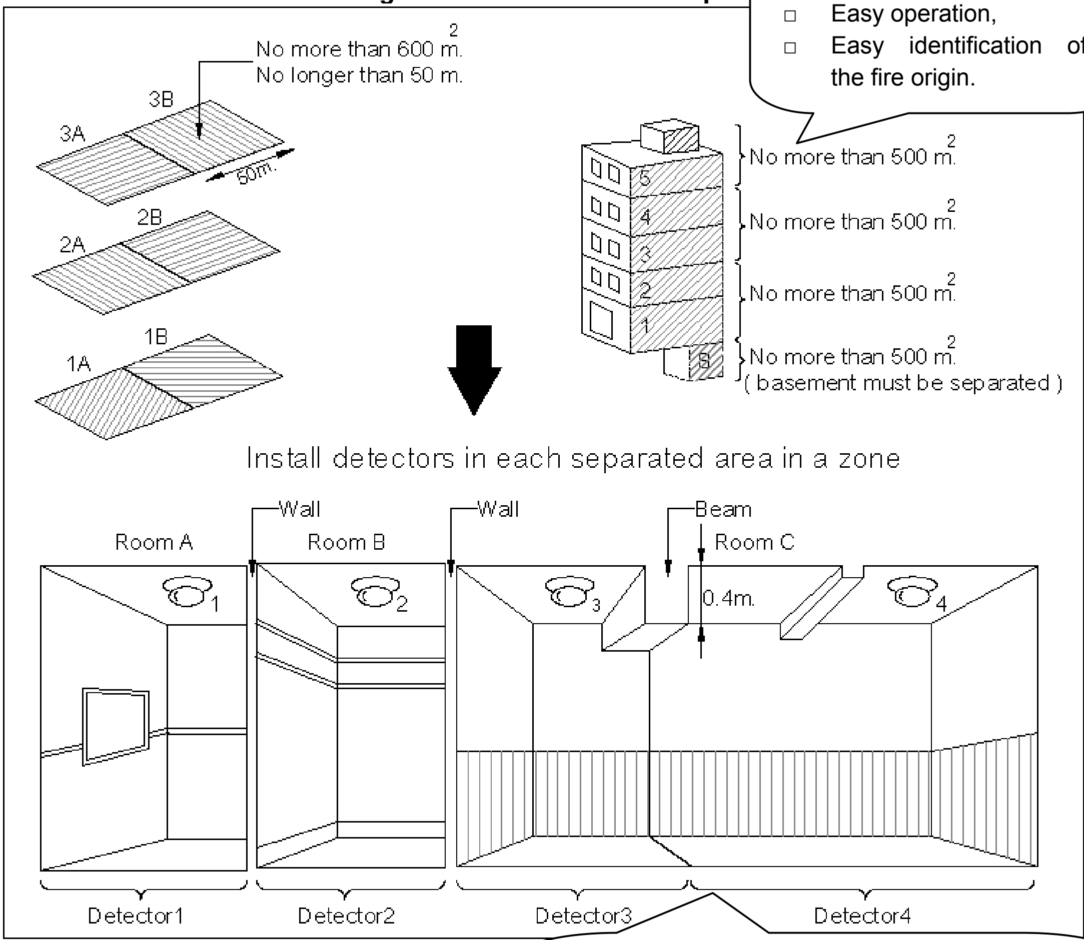
Note:
1) OK: Appropriate for the installed point
2) (OK): one or more types are appropriate or special treatment is necessary to install.

Heat Detectors

Heat detectors are a type of device that reacts to unusual heat and sends a signal. It is a general type of detector that forms a part of an automatic fire alarm system.

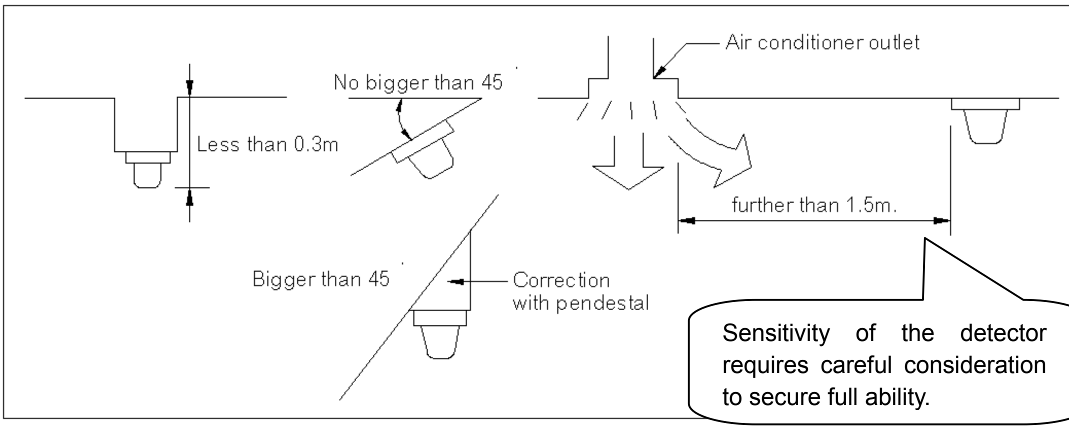
Zoning by certain floor area is necessary for;
- Easy operation,
- Easy identification of the fire origin.

Zoning for Heat Detectors in Japan



Heat detectors are necessary for every room and space separated by:
- Walls,
- Beams having the depth of more than 0.4m.

Standard of Spot-type Heat Detector Installation in Japan



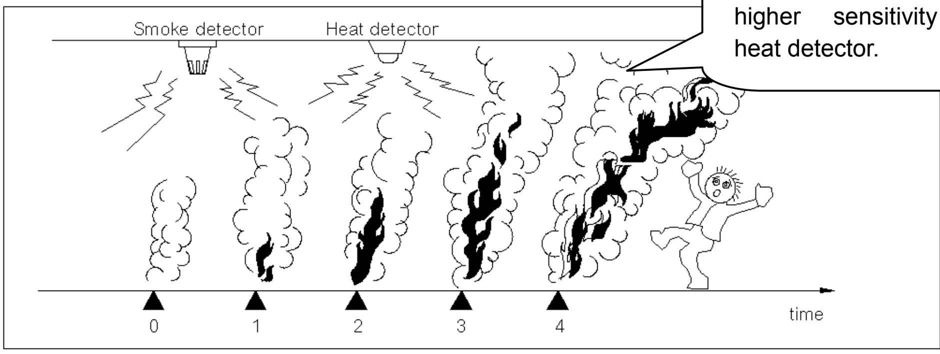
Sensitivity of the detector requires careful consideration to secure full ability.

Smoke Detectors

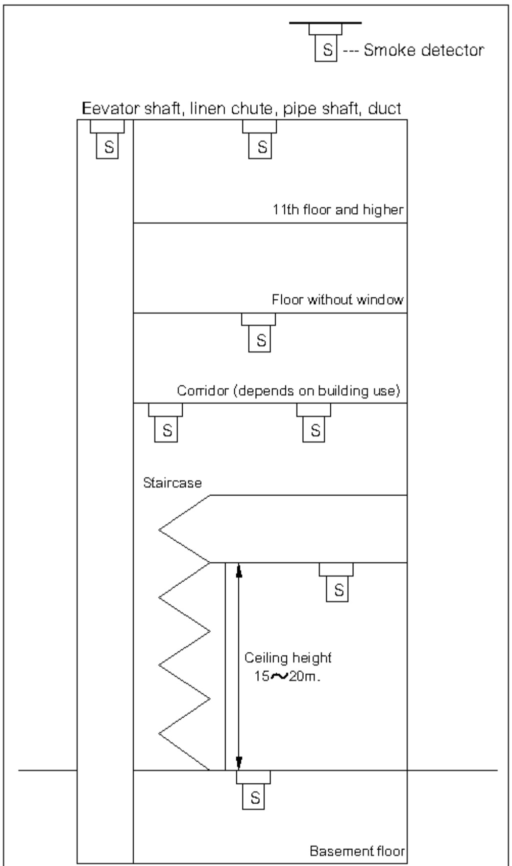
Smoke detectors react to smoke from fire before the temperature goes up enough to recognize an unexpected fire breakout. While it is a sensitive type of detector to be installed in specific situations, there are also some areas where the smoke detector should not be installed to avoid false alarms.

Sensitivity of Smoke Detector

Smoke detector has higher sensitivity than heat detector.



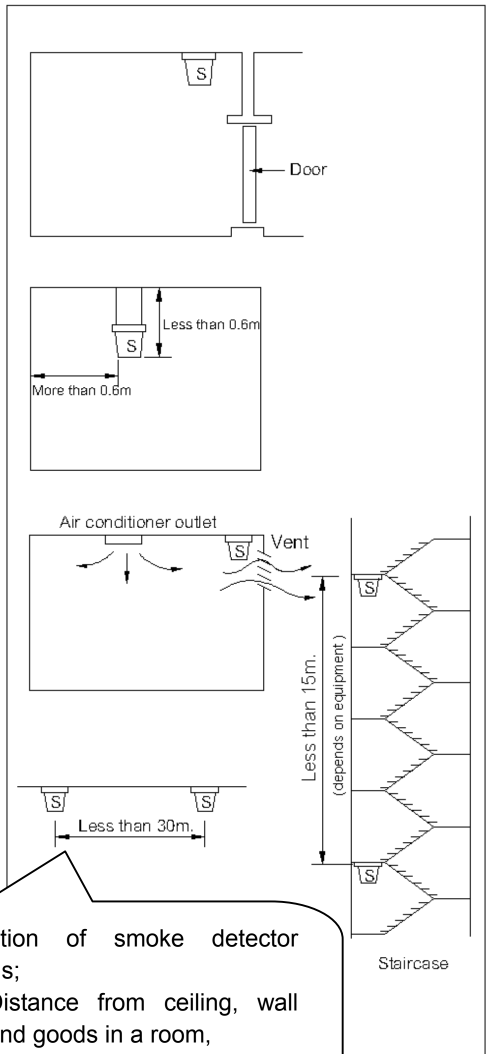
Areas where Smoke Detectors are required in Japan



Areas not appropriate for smoke detector

- Dust, fine powder, or vapor stays frequently.
- Corrosive gas can be produced
- Smoke is produced in normal use, such as kitchen.
- Temperature tends to be very high.
- A lot of smoke can come in sometimes.
- Water tends to be condensed.
- Something seems to affect the function of smoke detector.

Standard of Installation in Japan



Location of smoke detector needs;

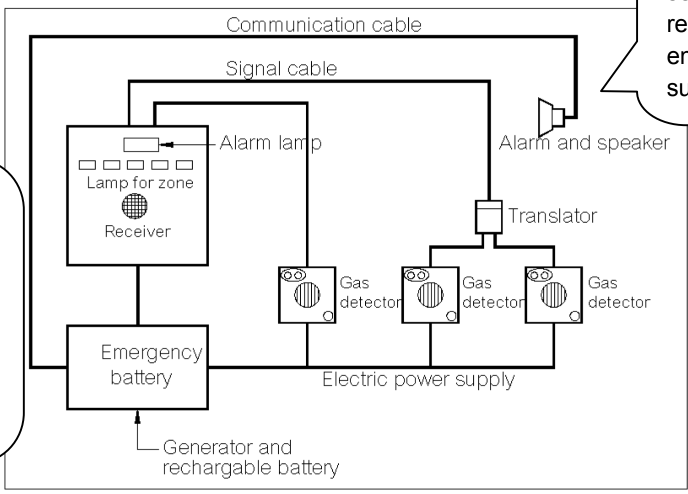
- Distance from ceiling, wall and goods in a room,
- Suitability of air flow in a room.

Gas Leakage Alarm and Indication System

This type of system works by detecting increasing concentrations of flammable gasses and activating an indicator and alarm. Gas leakage can cause not only poisoning, but also explosion and large fires. Therefore gas leakage should be found as soon as possible to be corrected.

A Gas detector sends a signal to a receiver and has emergency power supply.

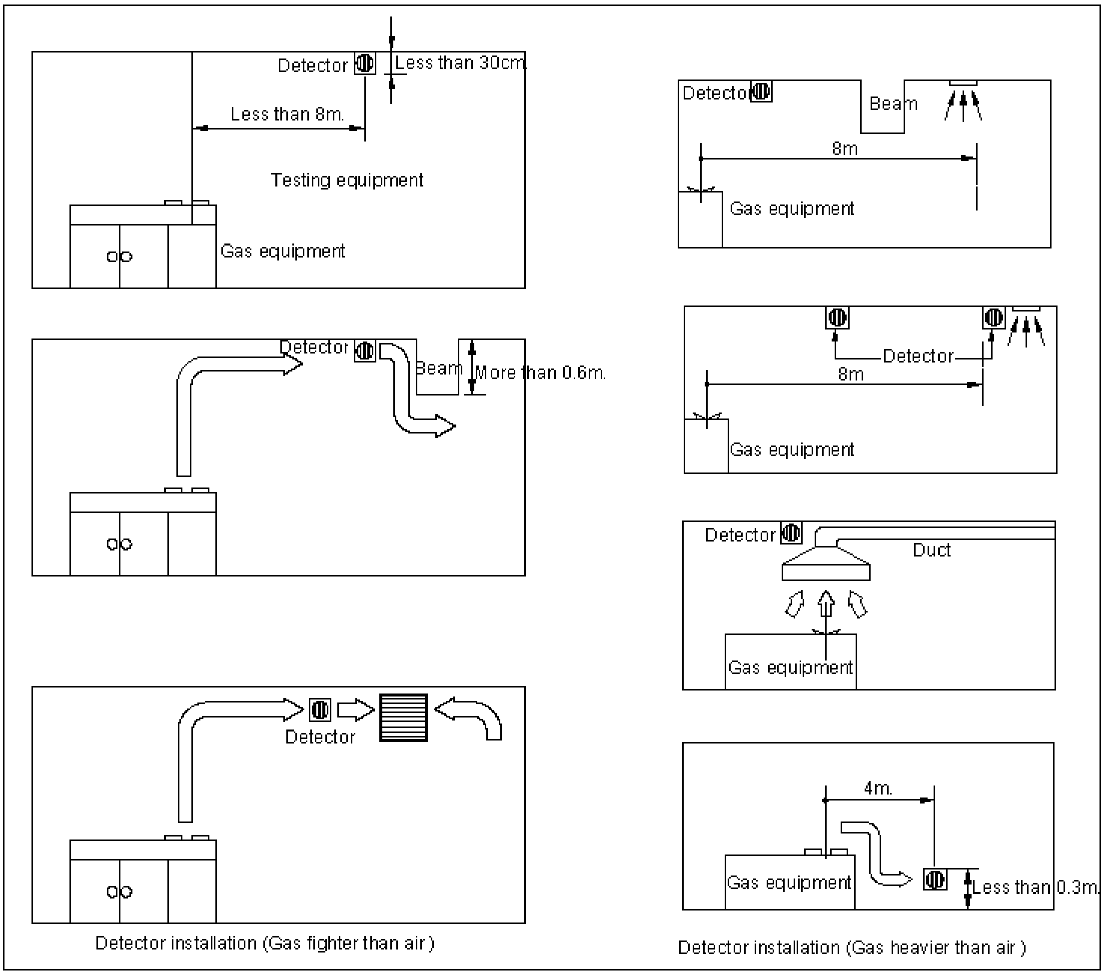
Gas Leakage Alarm and Indication System



Location of gas detector needs:

- Distance from ceiling, wall and goods in a room,
- Adaptation to air flow and specific gravity.

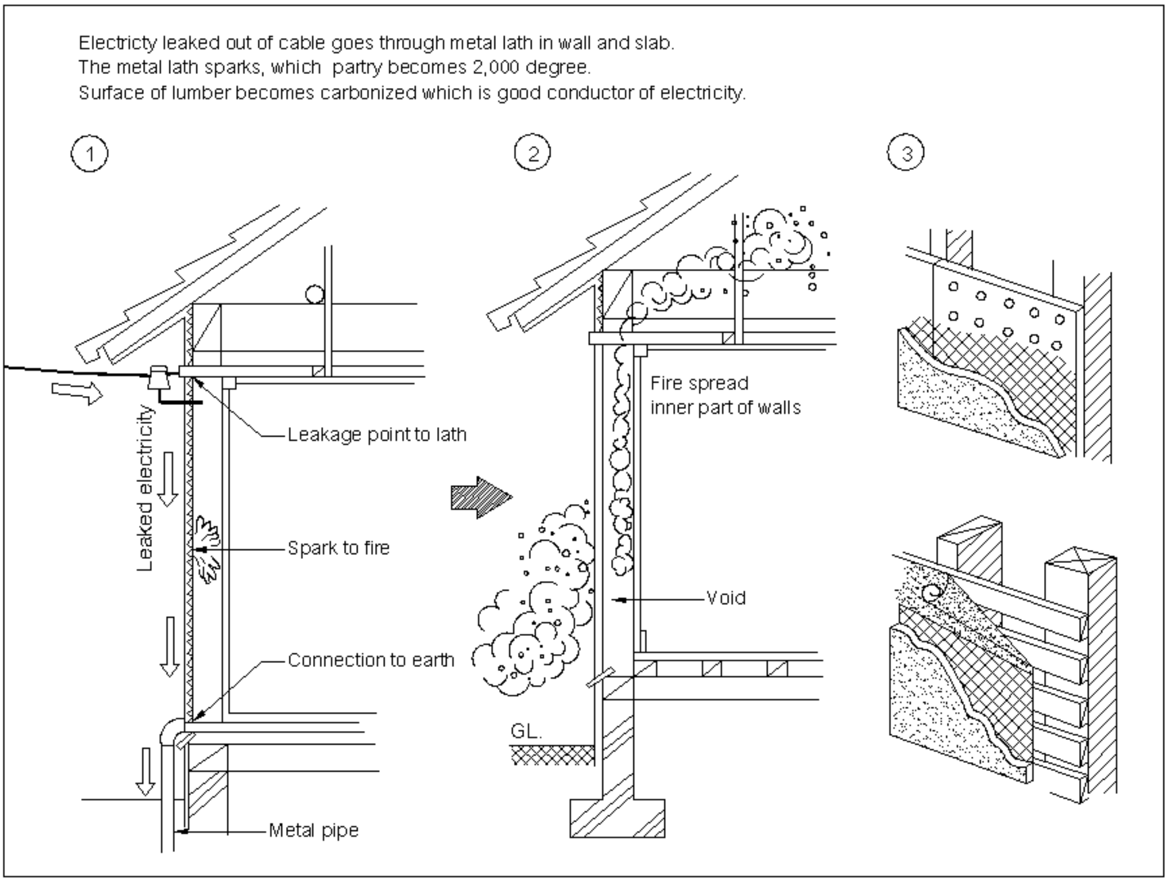
Standard of Installment of Gas Leakage Detector in Japan



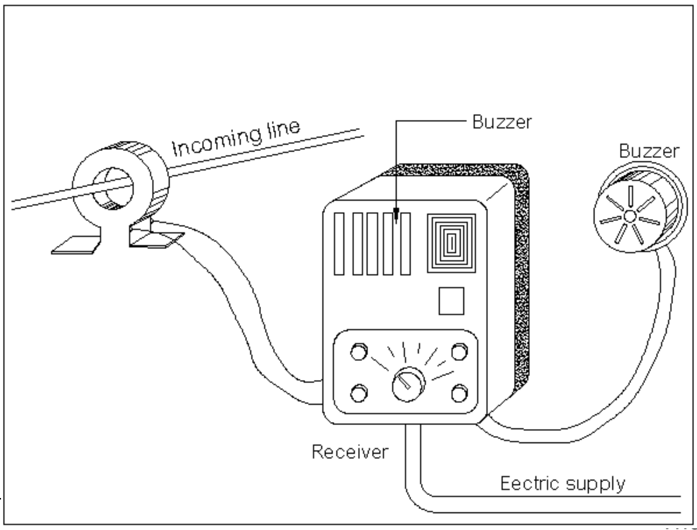
Electric Leakage Alarm System

Fire may sometimes break out by electric leakage in walls and slabs of metal lath and plaster. This type of fire breakout is difficult to find at an early stage, since the fire may breaks out from different points and slowly expand through the inside of walls and slab. To prevent this process, electricity should be monitored to ensure that it flows correctly.

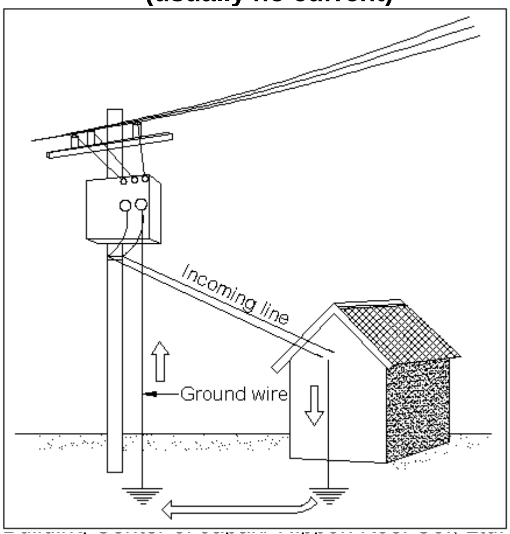
Typical Process of Fire by Electric Leakage in Wall



Electric Leakage Alarm System



Flow of Electric Current (usually no current)



2.1.7	Outbreak	**Initial Fire**	Fire Spread	Evacuation	Fire Fighting	Collapse	Exposure Fire

Fire Alarm System to Fire Department

The outbreak of fire should be informed to the fire department for professional help. Most of the time reporting is done by telephone. Before telephones became widespread, special alarm systems to the fire department and/or police station was necessary for many buildings. Now, however, there are still some buildings where an alarm system to the fire department is required.

Reporting System to Fire Department and Police Station

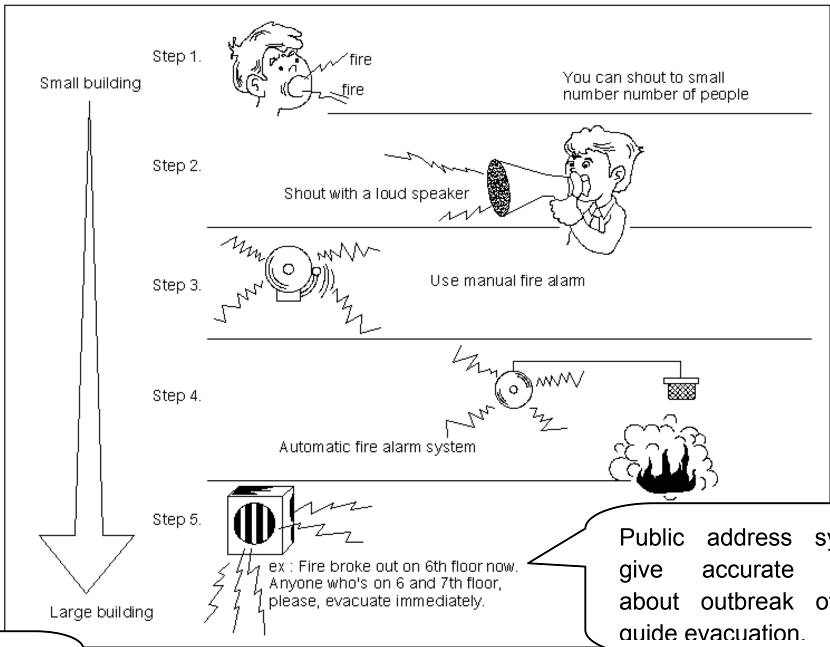
Buildings that have occupants sleeping inside are critical, since sleeping occupants take longer to find and react to fire. Buildings listed below are required to have automatic information systems other than telecommunication.

□ Hotel or other temporally accommodation, hospital, clinic, residential for the aged.

Emergency Alarm System (1/2)

After fire is detected, related people must be informed as soon as possible. The methods can be simple and by human when the buildings are small, but for a larger number of occupants and to larger areas, specialized equipment should be used.

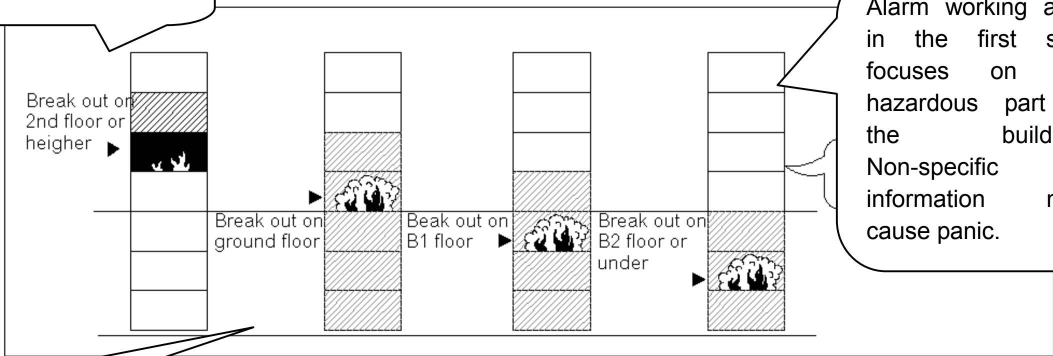
Effective Method by Size of Building



Public address system can give accurate information about outbreak of fire and guide evacuation.

Alarming on the floor under fire and upstairs

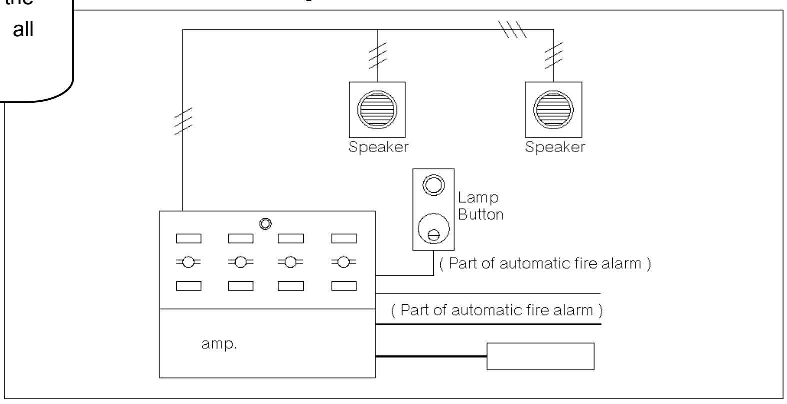
First Step of Automatic Fire Alarm Working Area



Alarm working area in the first step focuses on the hazardous part of the building. Non-specific information may cause panic.

Alarming on the ground, 2nd and all basement floors.

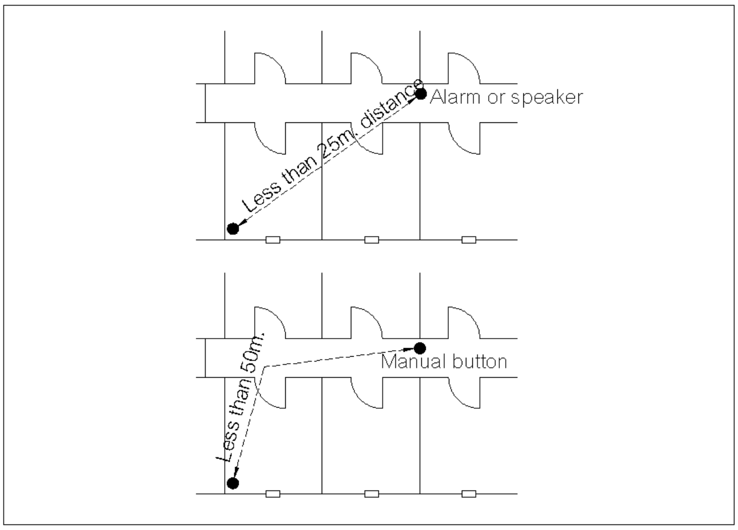
Communication System with Automatic Fire Alarm



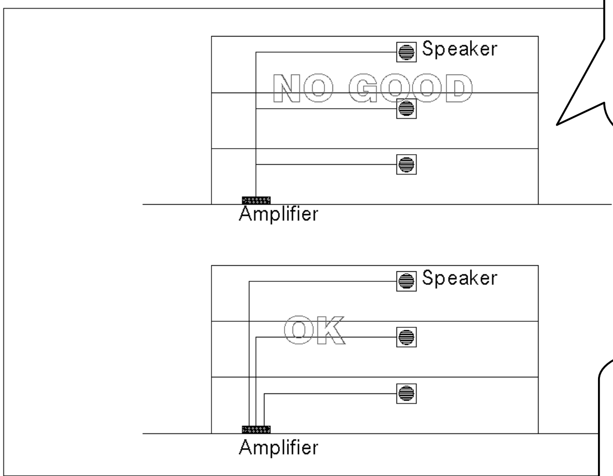
2.1.8	Outbreak	**Initial Fire**	Fire Spread	Evacuation	Fire Fighting	Collapse	Exposure Fire

Emergency Alarm System (2/2)

Straight Distance to Fire Alarm and Walking Distance to Manual Button



Separation of Cable Connection



Cable connection is separated.
If all connection comes together, it has risk of whole system shut down.

Type of emergency alarm system relates to the number of occupants and floors.

Necessity of Emergency Alarm System in Japan

Classification	Emergency alarm tool or Automatic siren or, Public address system	Fire alarm + automatic siren or Public address system	Fire alarm + public address system or Automatic siren + public address system	
	(Occupants)	(Occupants)	(Floor)	(Occupants)
Hotel	-	20 or more	11th above GL or 3rd below GL	300 or more
Office	-	50 or more	ditto	-
Theater	-	ditto	ditto	300 or more
Hospital	-	20 or more	ditto	ditto
School	-	50 or more	ditto	800 or more
Factory	20-49	ditto	ditto	-
Multi-story housing	-	ditto	ditto	800 or more
Deartment store	20-49	ditto	ditto	300 or more

Principle of Initial Fire Extinguish

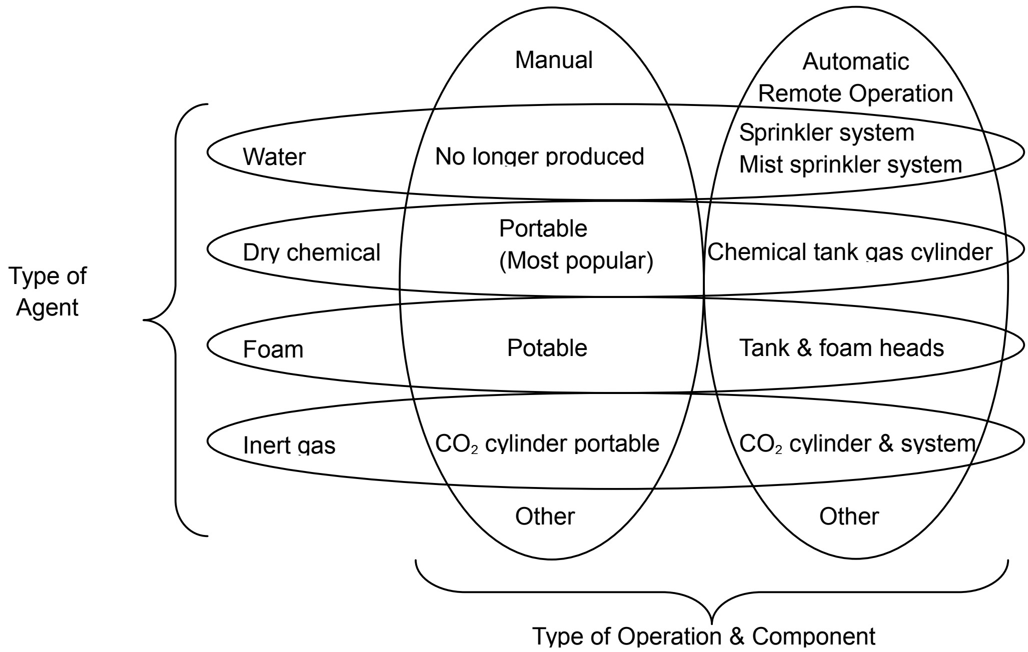
The initial response to extinguish a fire is important, since it is very demanding to extinguish fire once it has spread. On the contrary, occupants can extinguish a fire before it has developed too much. Therefore the initial fire extinguishing comes immediately after detection of the fire and if successful can prevent a lot of damage or loss.

What kind of extinguisher can be classified in terms of operation method and its components:

□ Agent: 1) water, 2) dry chemical, 3) foam, and 4) inert gasses,

□ Operation method: manual or automatic remote operation.

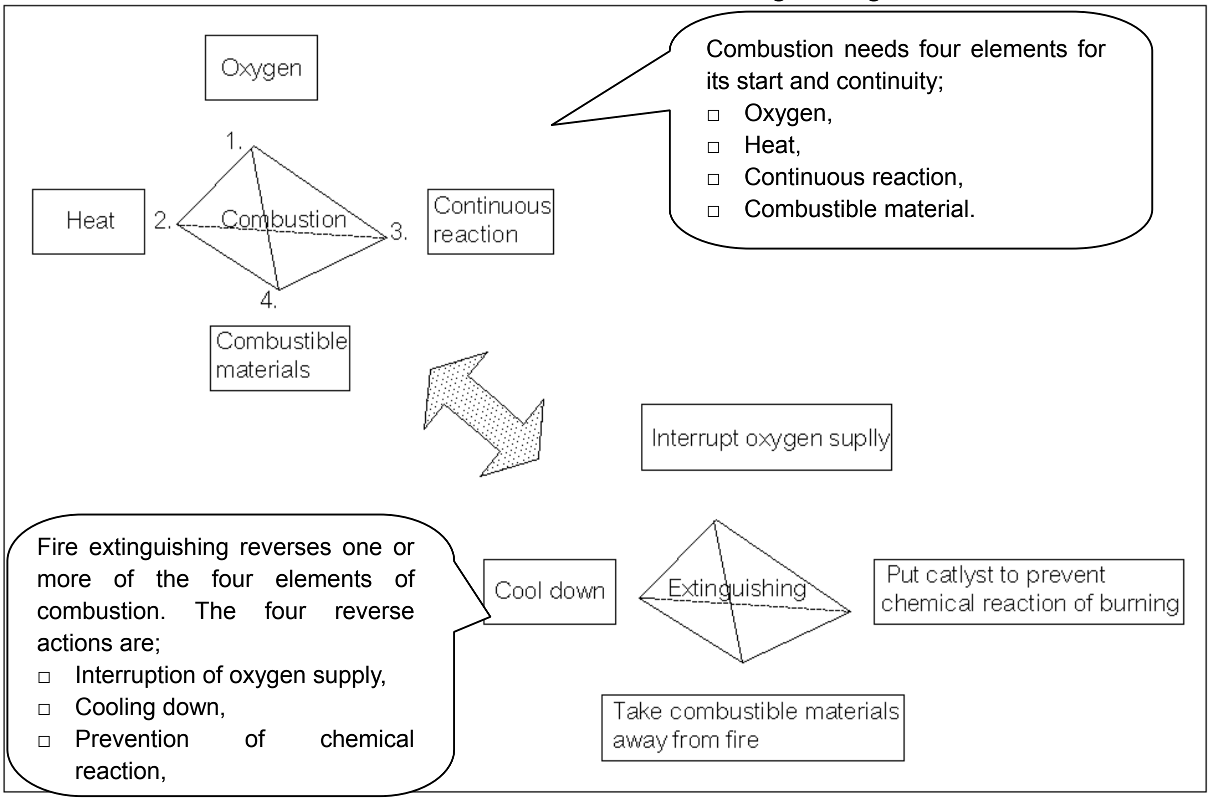
Classification of Initial Fire Extinguishing System



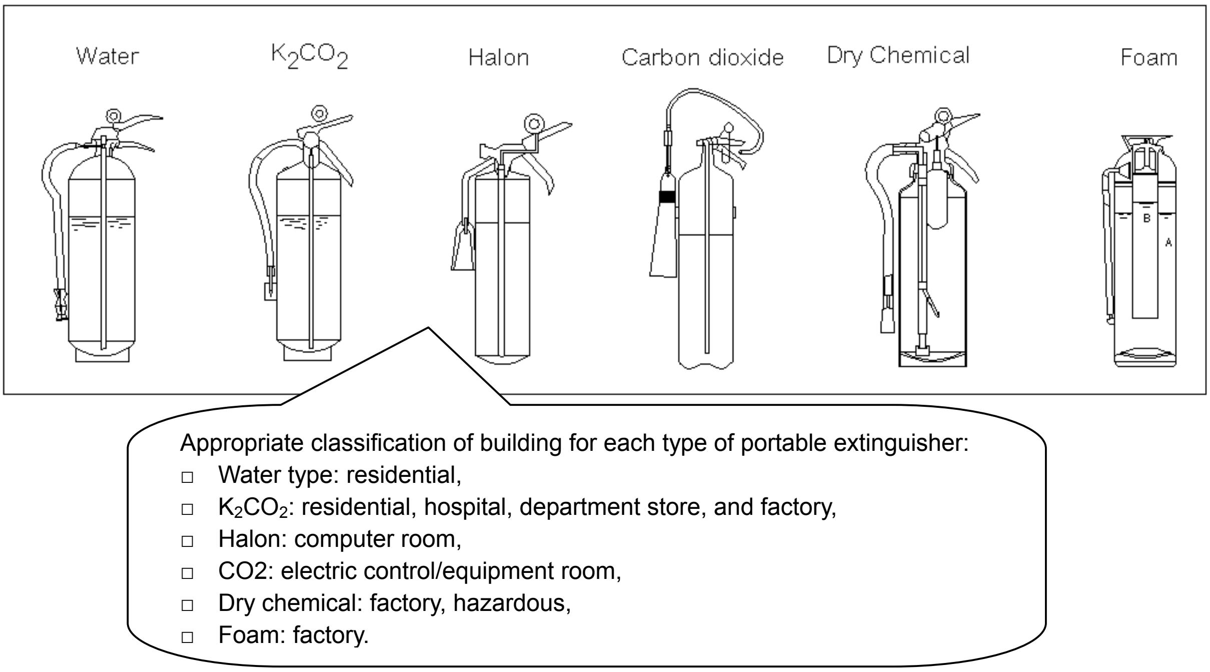
Portable Fire Extinguishers

Portable fire extinguishers can be easily placed in any kind of building or facility. Whenever somebody finds a fire, it is quite simple for him or her to pick up the nearest portable extinguisher and spray agent on the fire.

Elements of Combustion and Extinguishing



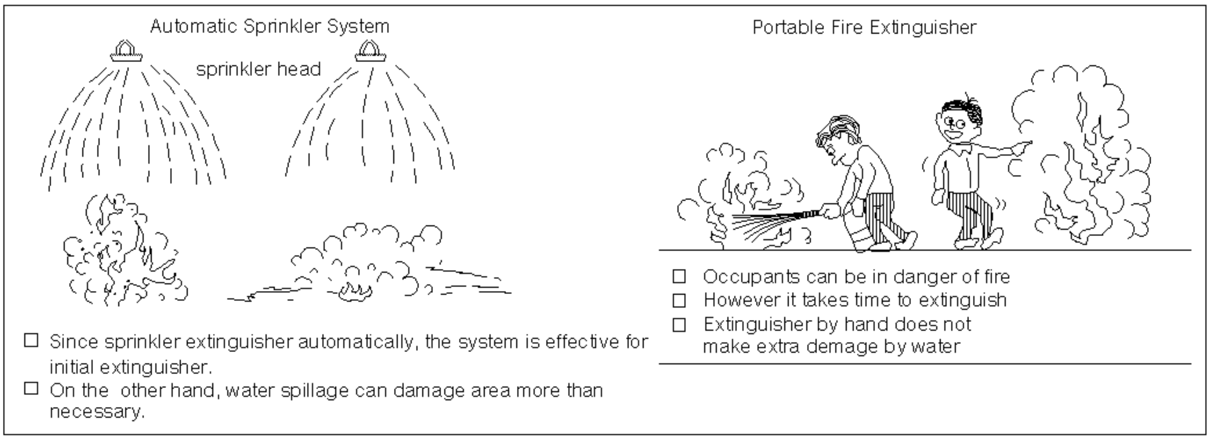
Type of Portable Fire Extinguisher



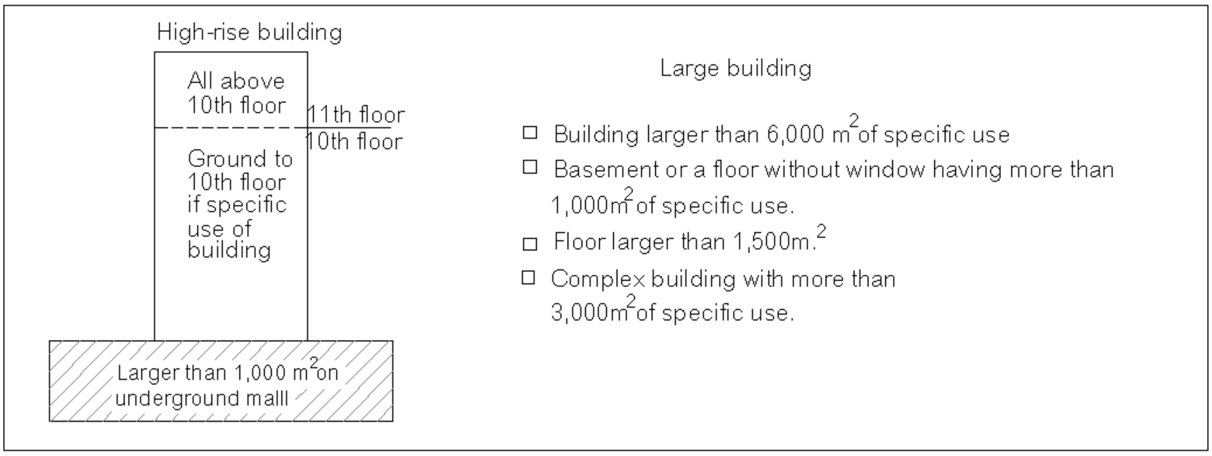
Automatic Sprinkler System (1/2)

The advantage of sprinkler systems is that they can extinguish a fire without human operation in the burning area. The system usually consists of a water tank connected to sprinkler heads that are activated by a heat detector. In this case, sprinkler heads perform the role of heat detector as well as initial extinguishing.

Difference between Potable Fire extinguisher and Automatic Sprinkler System

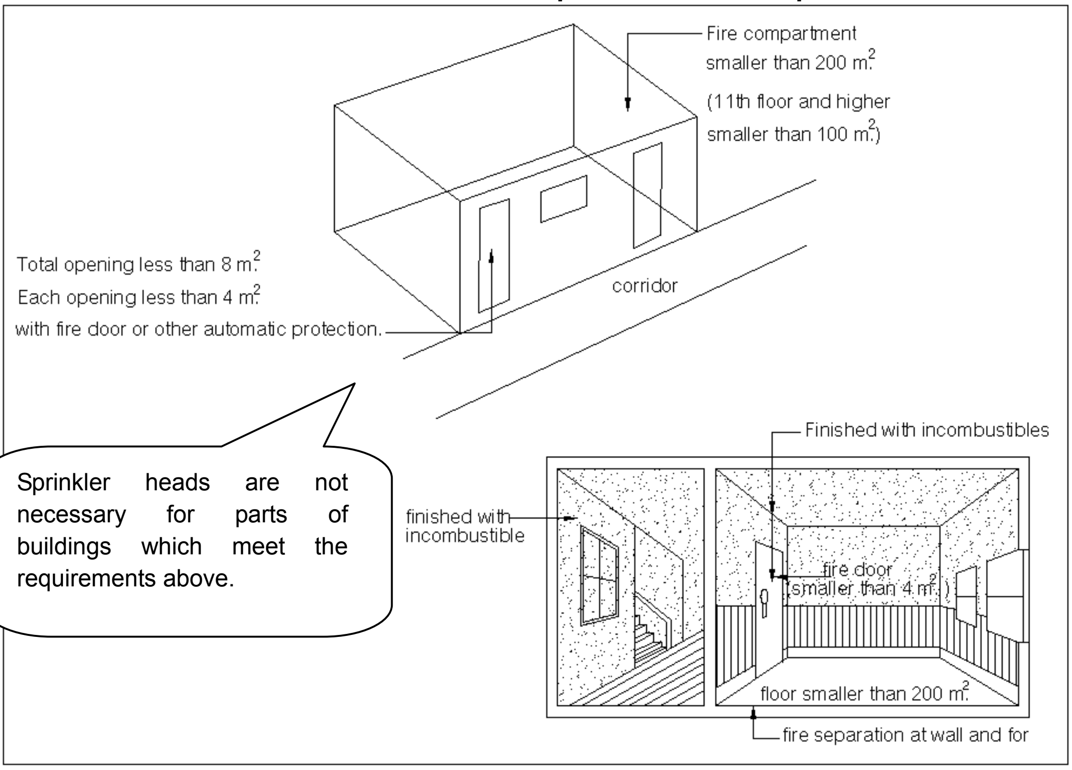


Necessity of Automatic Sprinkler System in Japan

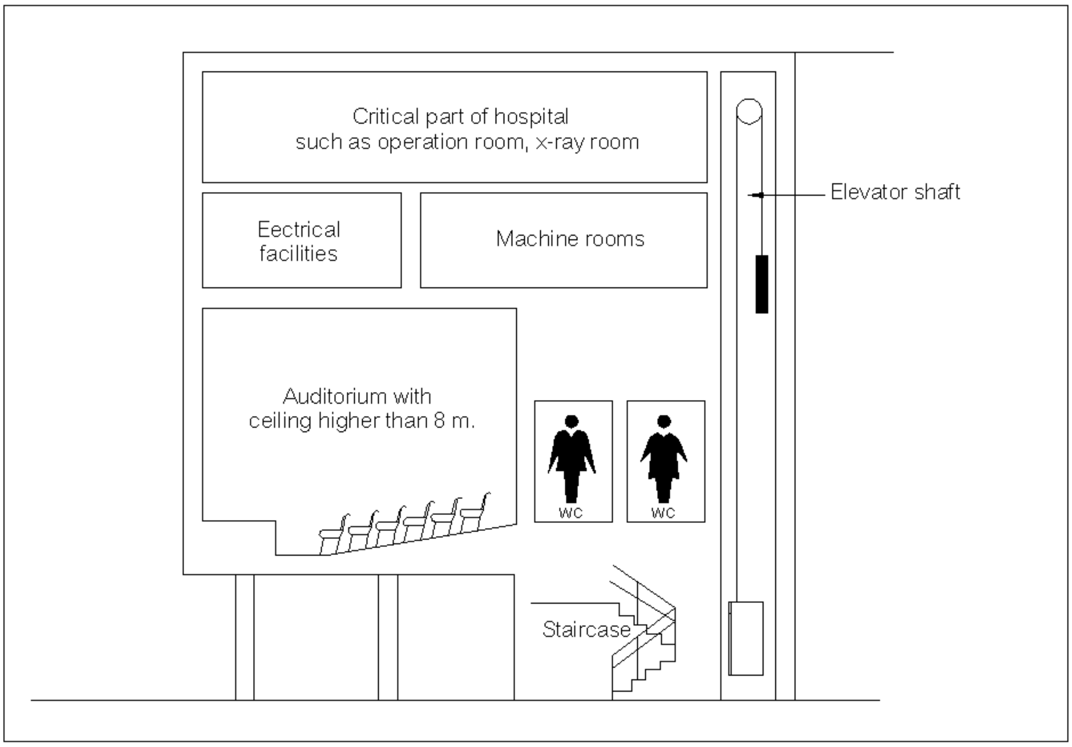


Automatic Sprinkler System (2/2)

Room that does not need Sprinkler Head in Japan



Part of Building that does not need Sprinkler Head in Japan



Necessity of Automatic Sprinkler System

Necessity of Automatic Sprinkler System in Three Countries

Classification	Thailand	Japan	United States
Hotel	A building; □ Higher than 23m, or □ Larger than 10,000 m^2 in total floor area.	A building having: □ 6,000 m^2 in total area and 2 stories, □ a floor of 1,500m^2 between 4th to 10th floor, □ 11 stories, □ Basement floor of 1,000 m^2.	Any building (except a building having no guestroom on the 3rd floor or higher)
Office	Ditto	A building higher than 10 stories.	A floor having; □ 139m^2 or more without window, Part of a building; □ Higher than 16.8 m from the range of ladder trucks.
Theater	Ditto	A building meeting with the necessity for Hotel.	An occupied area: □ Larger than 1,115 m^2 and with 300 occupants or more. A floor and part of a building meeting with the necessity for Office.
Hospital	Ditto	A building having: □ 6,000m^2 in total and 2stories, □ a floor of 1,500m^2 between 4th to 10th floor, □ 11 stories, □ Basement floor of 1,000 m^2.	Any building
School	Ditto	A building meeting the same specifications as for Office.	A occupied area: □ Larger than 1,858 m^2 below the safety floor. A floor and part of building meeting with the necessity for Office.
Factory	Ditto	Ditto	An occupied area; □ Larger than 1,115 m^2 and 300 or more occupants. A floor and part of building meeting the specifications as for Office.
Multi-story Housing	Ditto	Ditto	A building having; □ 16dwelling units or more, □ a dwelling unit on 3rd floor or higher. A floor and part of building meeting with the specifications as for Office.
Shophouse	Ditto	No definition of shophouse.	No definition of shophouse

Note: Necessity of the automatic sprinkler is referred to;
1) The Ministerial Regulations under the Building Control Act in Thailand,
2) The Fire Service Law in Japan,
3) The International Building Code in United States.

Necessity of the automatic sprinkler is different by classification of building in Japan and US.
US generally focuses on a high-rise building and large room, while Japan concentrates on large and high-rise buildings.

Type of Sprinkler Head

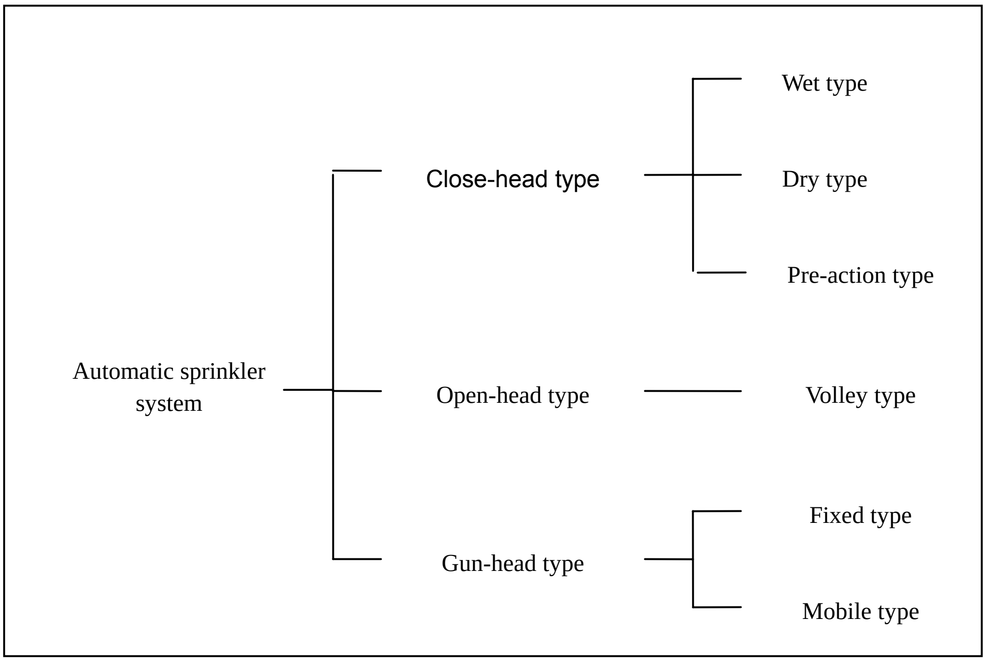
The automatic sprinkler system is classified into three types based on the sprinkler head;

□ Close-head type,

□ Open-head type,

□ Gun-head type.

Types of Automatic Sprinkler System



1)Close-head type: Ordinary type and having further three different types.

□ Wet-pipe type: Piping is filled with pressurized water at all time. It is useful for general buildings.

□ Dry-pipe type: Piping is filled with pressurized air at all time. When fire breaks out, water is supplied after the release of the pressurized air. This type is preferable for a building in regions susceptible to pipe freezing.

□ Pre-action type: Similar to the dry-pipe type, piping is filled with pressurized air. When fire breaks out, water is supplied after the detection of fire by fire detector and sprinkler head. This type is preferable for important parts of a building, such as a hospital, computer room, and housing.

2)Open-head type: Piping is filled with an atmosphere in a room. In case of fire, the system starts manually or automatically by a fire detector. This type is useful for the stage in a theater.

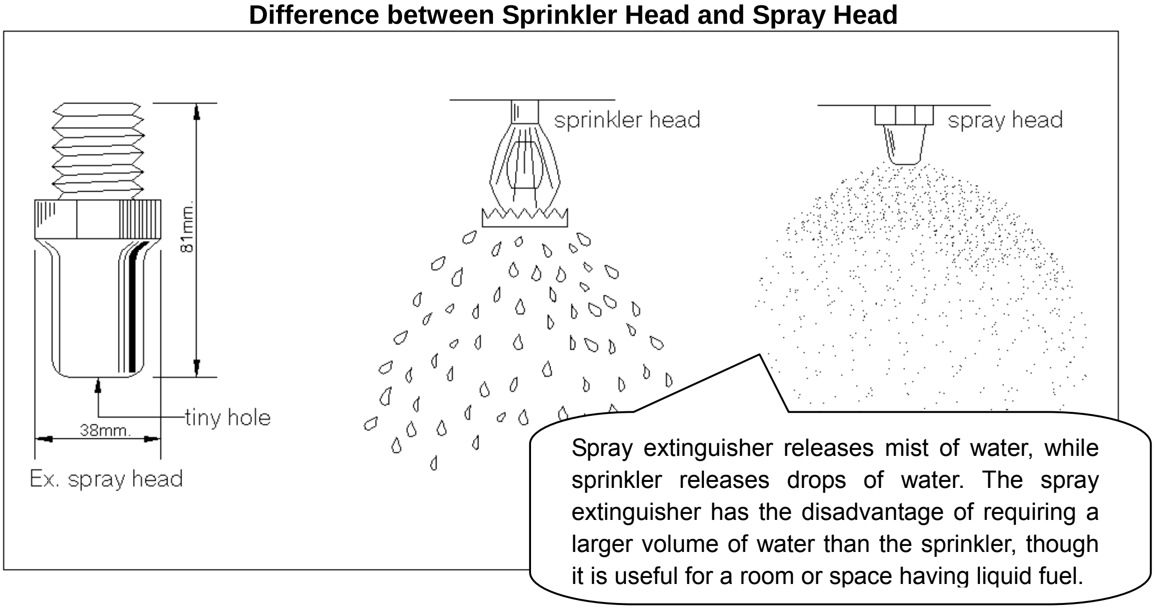
3)Gun-head type: Preferable for a part of room or building with high ceiling (>10 m).

Water Spray Extinguishing System (1/2)

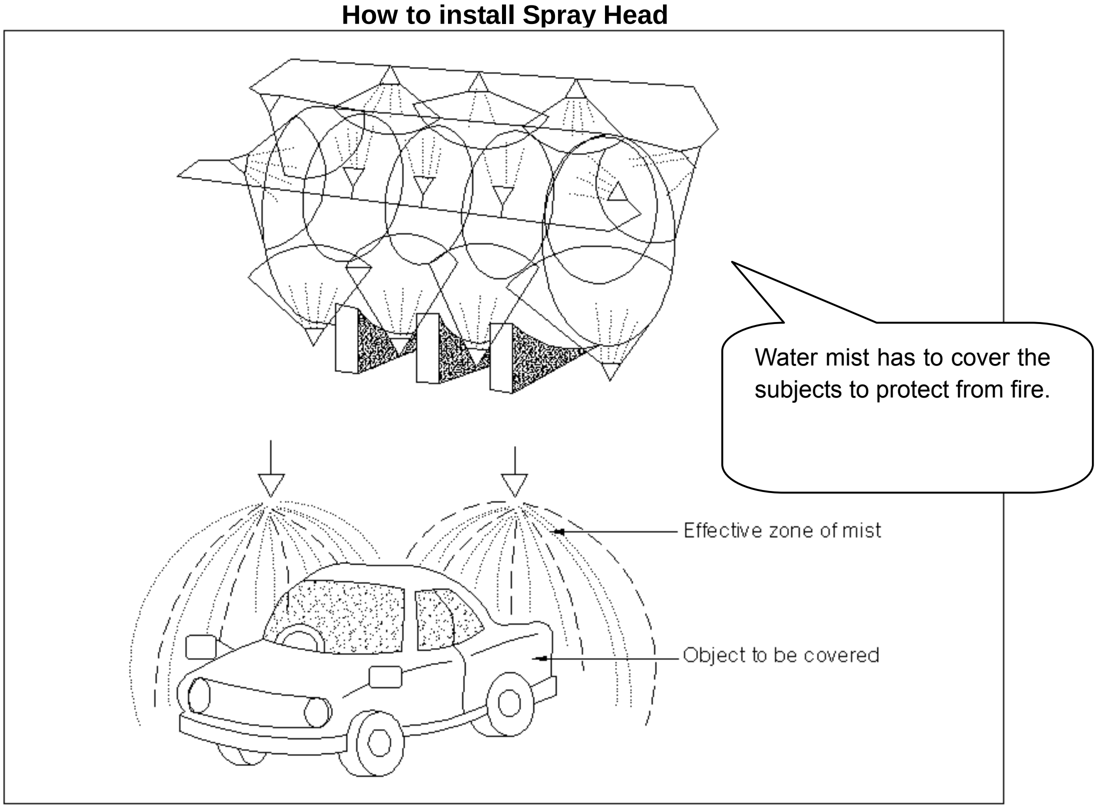
The water spray extinguishing system discharges water mist. It has the advantage of cooling and suffocation of the fire. The mixture of air and water produces a floating cloud substance. In oil fires, this substance covers the liquid surface and suppresses the evaporation of oil. This physical characteristic extinguishes the fire

The water spray extinguishing system is preferable for parking, liquefied petroleum gas (LPG) tank, liquefied natural gas (LNG) tank and oil tank.

Difference between Sprinkler Head and Spray Head

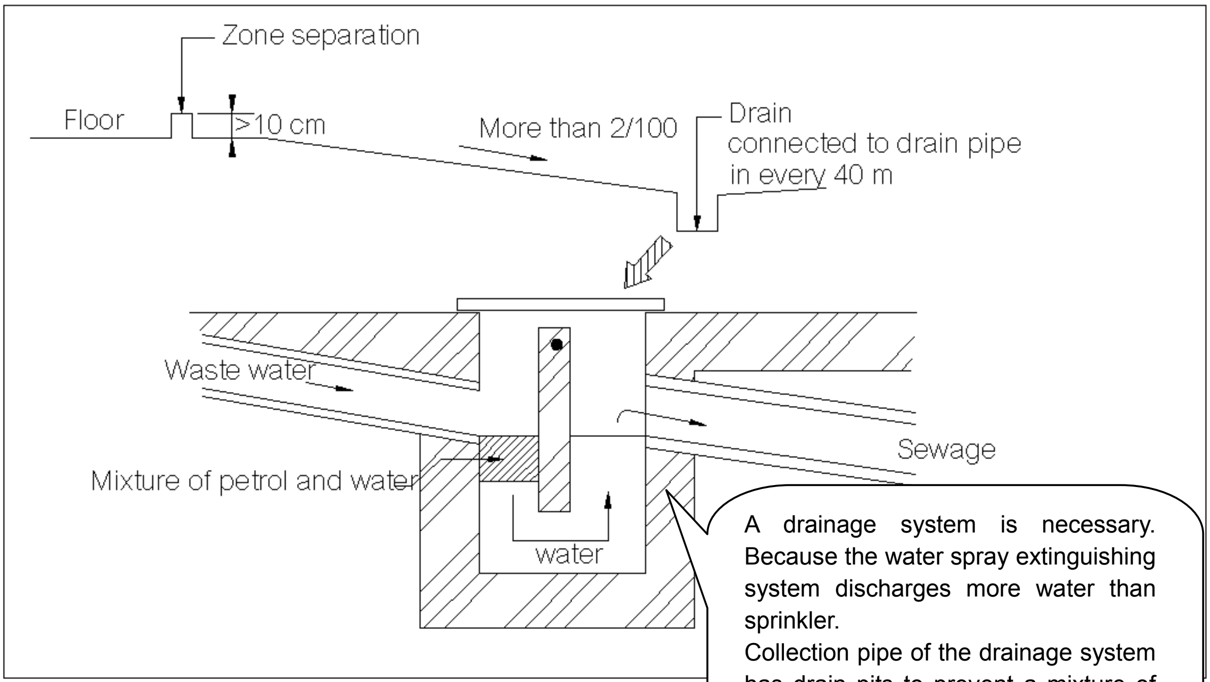


How to install Spray Head



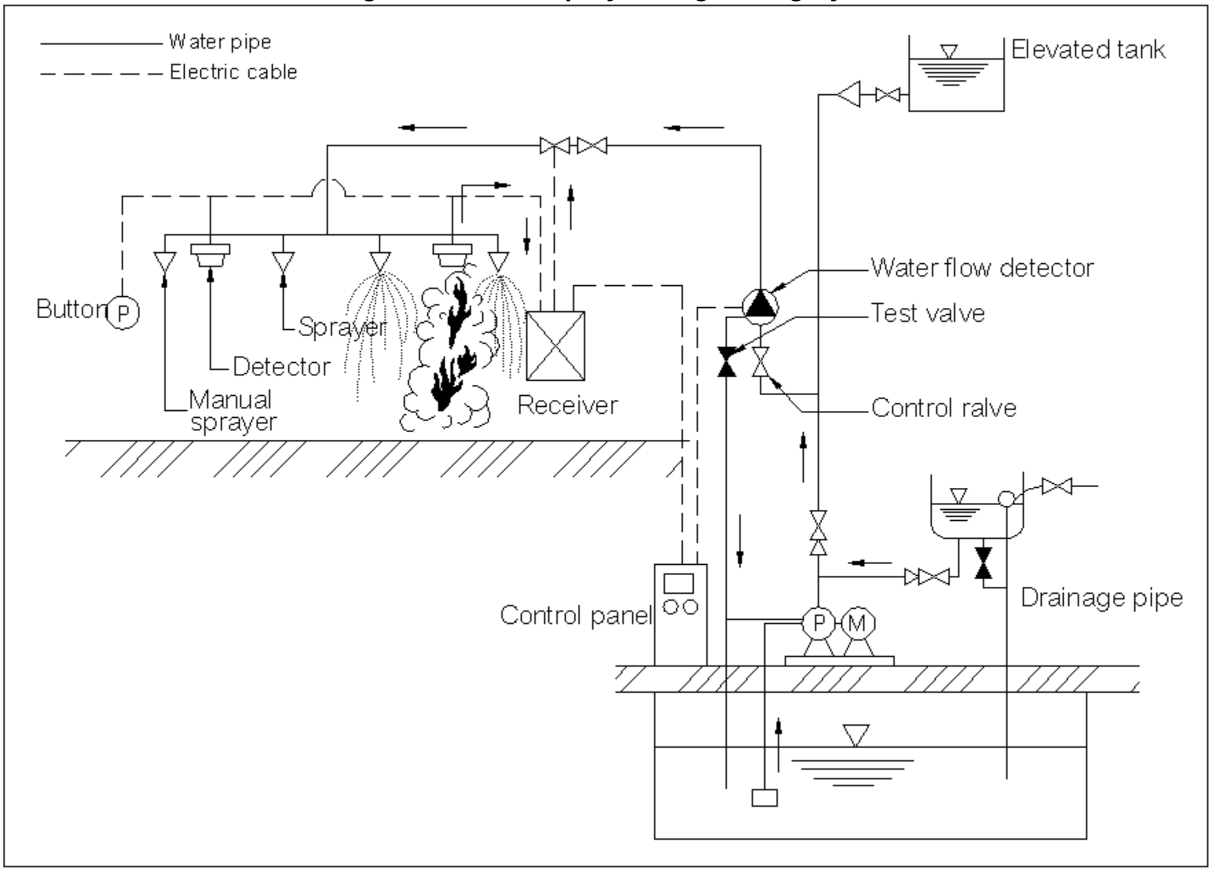
Water Spray Extinguishing System (2/2)

Drainage System for Water Spray Extinguishing System



A drainage system is necessary. Because the water spray extinguishing system discharges more water than sprinkler.
Collection pipe of the drainage system has drain pits to prevent a mixture of water and liquid fuel from spreading.

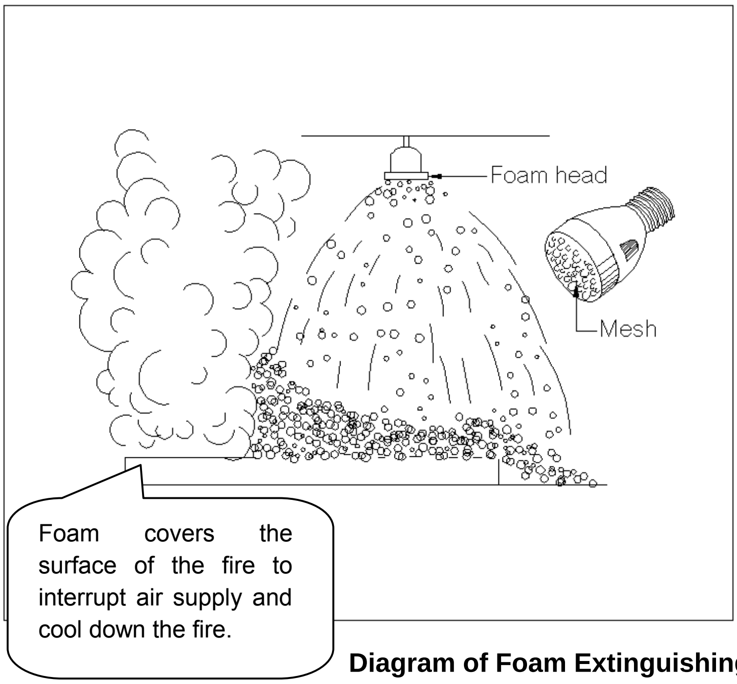
Diagram of Water Spray Extinguishing System



Foam Extinguishing System

In liquid fuel fires, ineffective use of sprinklers and hydrants helps the fire spread. A foam extinguishing system is preferable for extinguishing the fire of flammable liquid. It provides the foam, which is a mixture of water, air, and foam agent. The foam covers the surface of the fire to interrupt oxygen supply and cool down the fire.

How to install Foam Head



Type of Foam Head

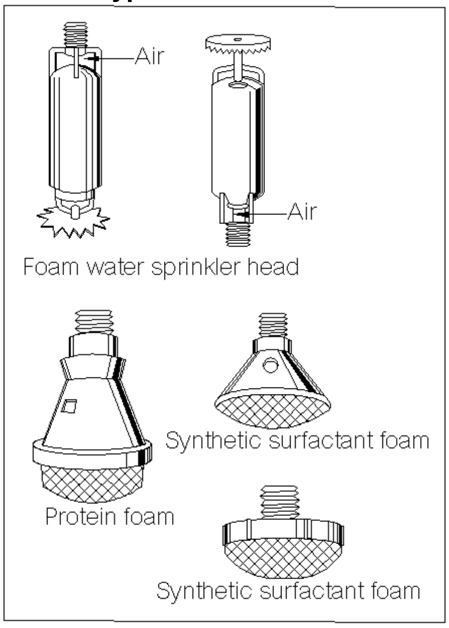
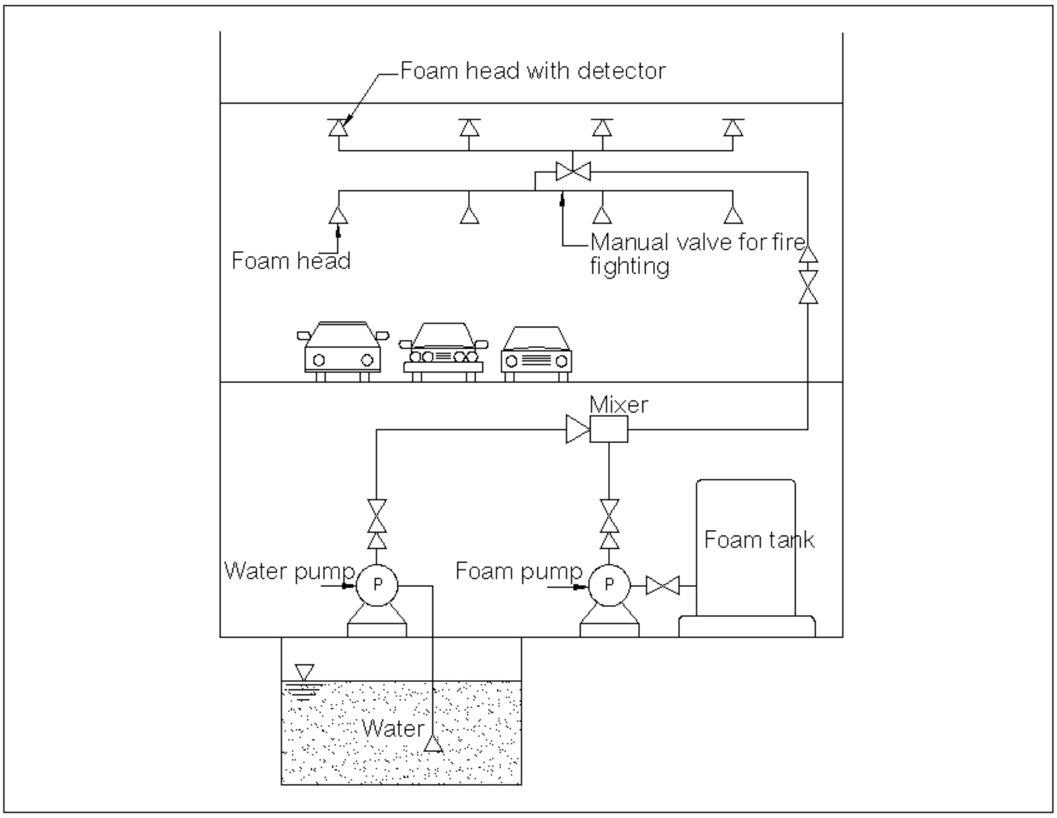


Diagram of Foam Extinguishing System

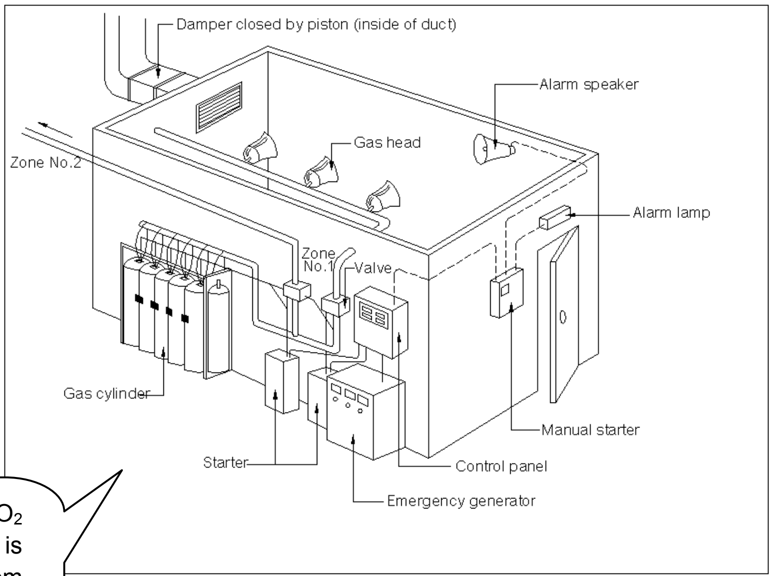


Carbon Dioxide Extinguishing System

Carbon dioxide (CO2) is noncombustible and has a greater specific gravity than air. The CO_2 extinguishing system suppresses the fire by interruption of oxygen supply to the fire.

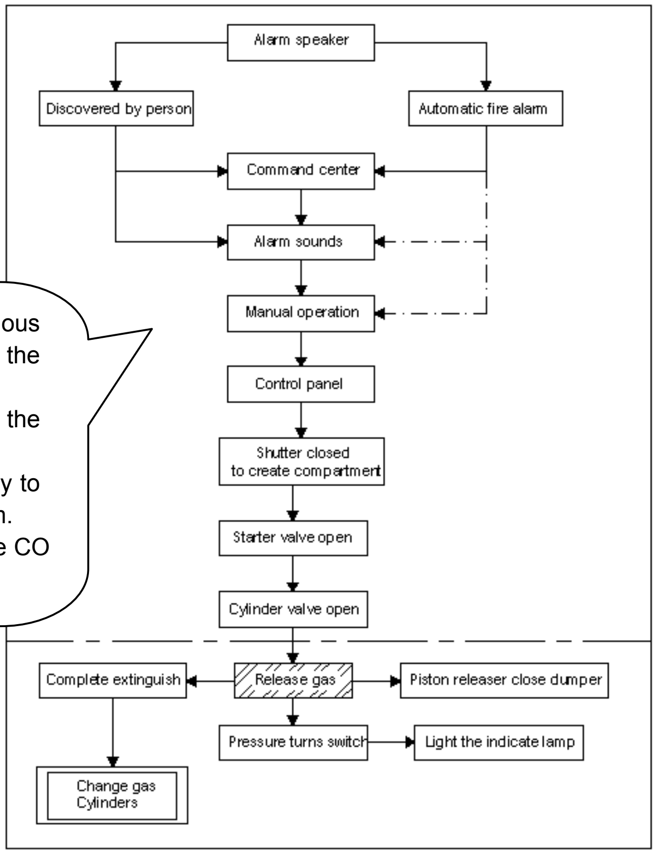
The CO_2 extinguishing system has the advantage of causing no damage to the building structure, is non-conductive of electricity, and is safe to store, while it has the disadvantages of requiring high pressure-resistant piping, and high precaution of life safety.

Installment of CO_2 Extinguishing System



Equipment for a CO_2 extinguishing system is located separately from the room that it is designed to protect.

Process of stating CO_2 Extinguisher



High concentration of CO_2 is hazardous for mankind. Before activating the system:

- Occupants must evacuate from the room,
- The room must be enclosed tightly to secure effectiveness of the system.

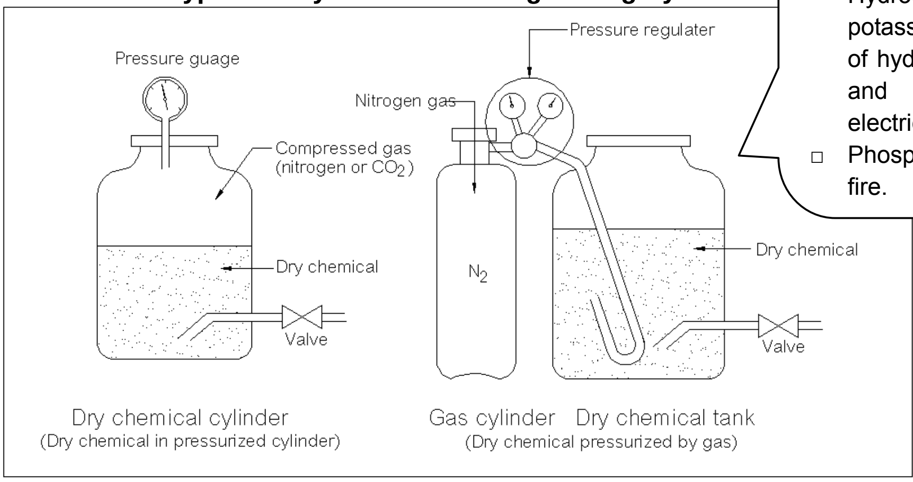
Manual operation is mandatory for the CO extinguishing system.

Dry Chemical Extinguishing System

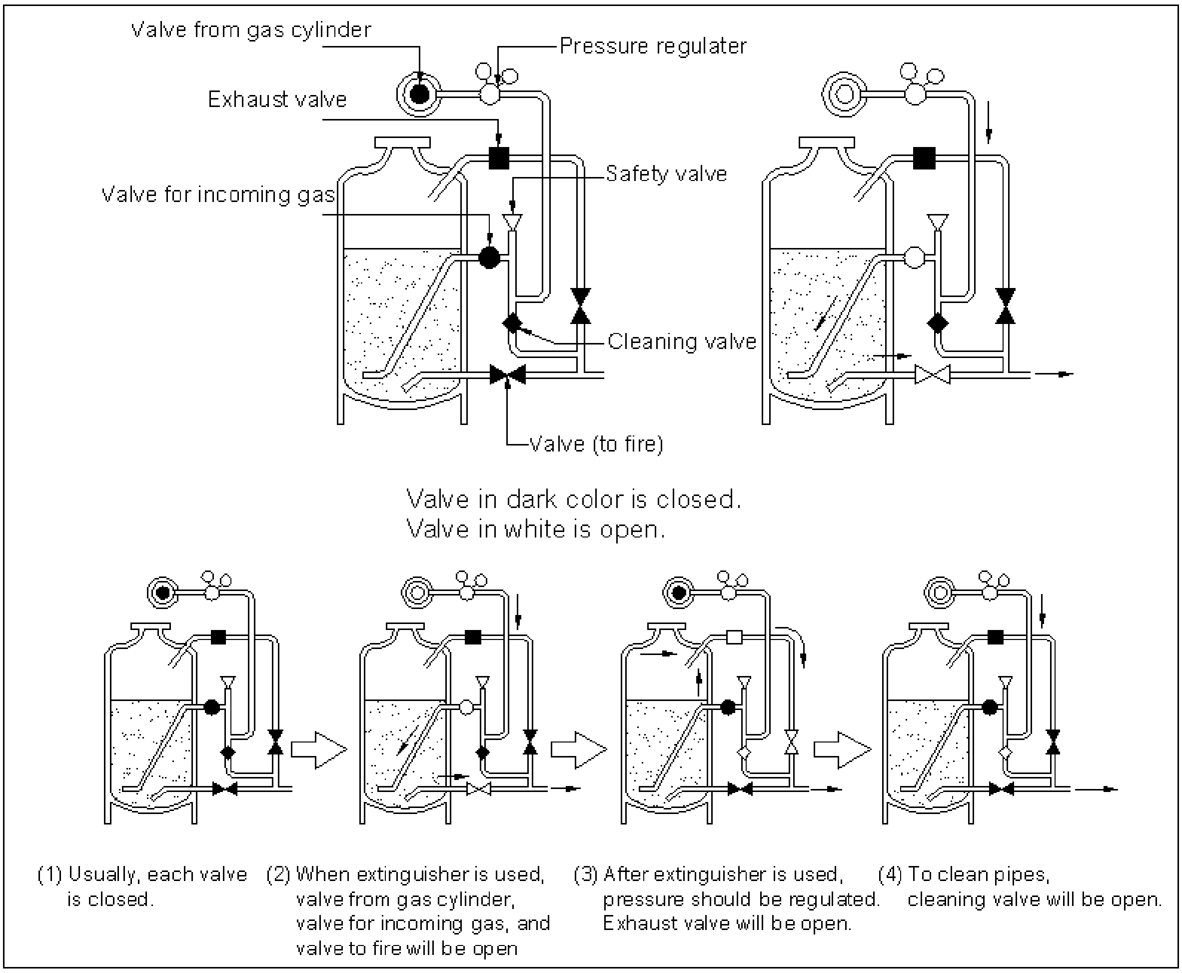
The dry chemical extinguishing system works by spraying dry chemical agent with pressurization provided by nitrogen and carbon dioxide.

Dry chemical systems have various agents:
- Hydrocarbon sodium Hydrocarbon potassium, and Mixture of hydrocarbon sodium and urea: oil and electric fire,
- Phosphate: all kinds of fire.

Types of Dry Chemical Extinguishing System



Operation of Dry Chemical Extinguishing System



Principle of Noncombustible Interior Finish (1/2)

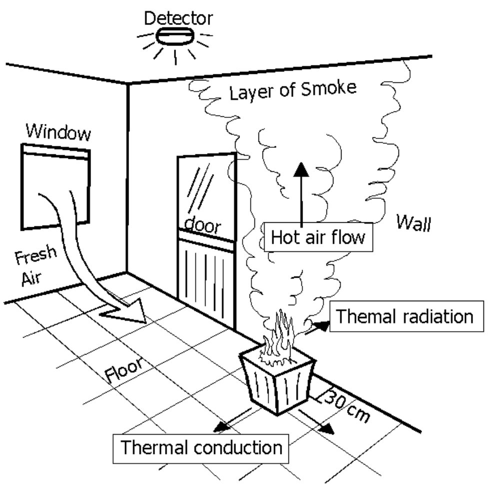
Rapid development of fire causes much damage to a building and hinders evacuation and fire fighting. The fire also generates smoke consisting heated and toxic gases which is often fatal to occupants. The noncombustible interior finish aims to:

□ Prevent the outbreak of fire,

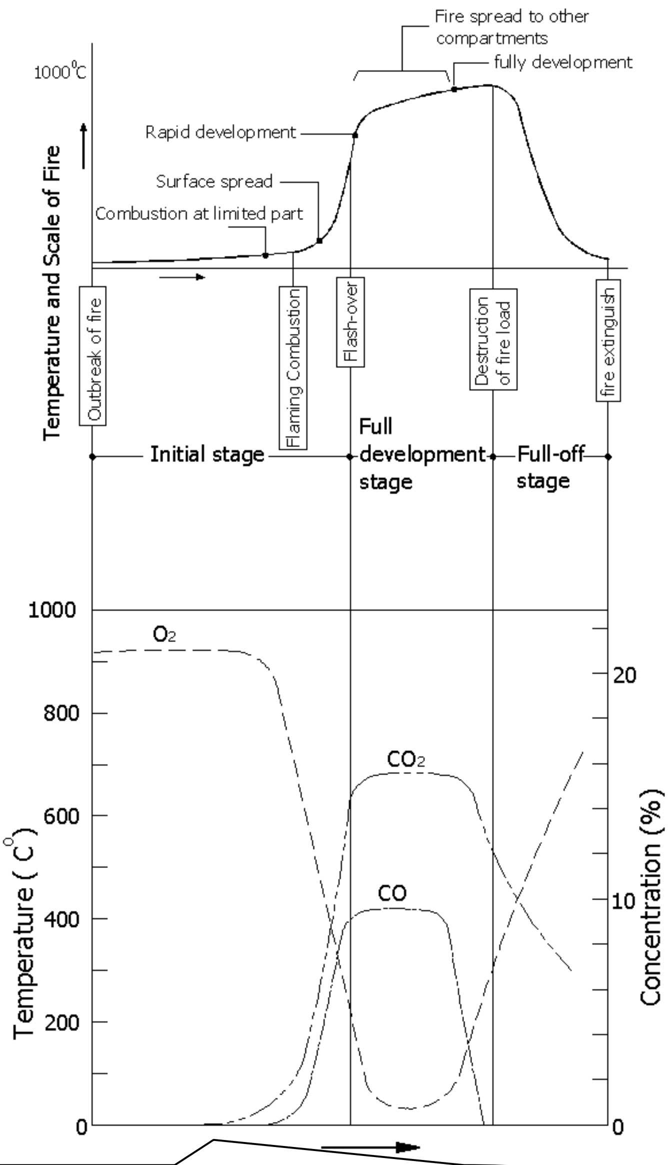
□ Retard the development of fire,

□ Prevent generation of smoke and toxic gases.

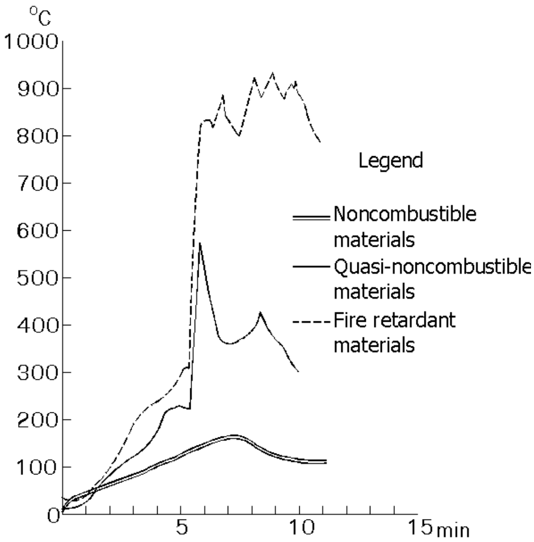
Three Elements of Heat Transmission



Temperature and Gases by Stage of Fire



Temperature-Time Curve by Noncombustible Material



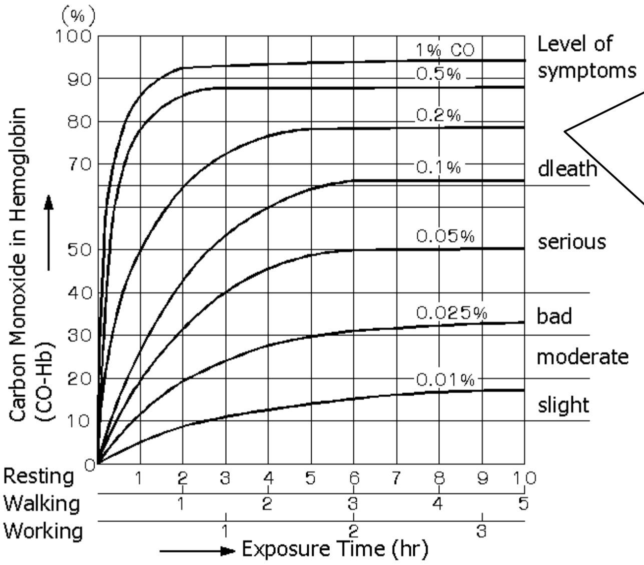
Flash-over is defined as the conditions that fire heats the combustible materials in a room under fire to the point where all combustibles are simultaneously ignited. In and after the flash-over, the conditions in the room become threatening to occupants. The conditions are:

□ Extremely high temperature,

□ High concentration of CO and CO_2 and low concentration of O_2.

Principle of Noncombustible Interior Finish (2/2)

Level of Symptoms by Exposure Time and CO Concentration



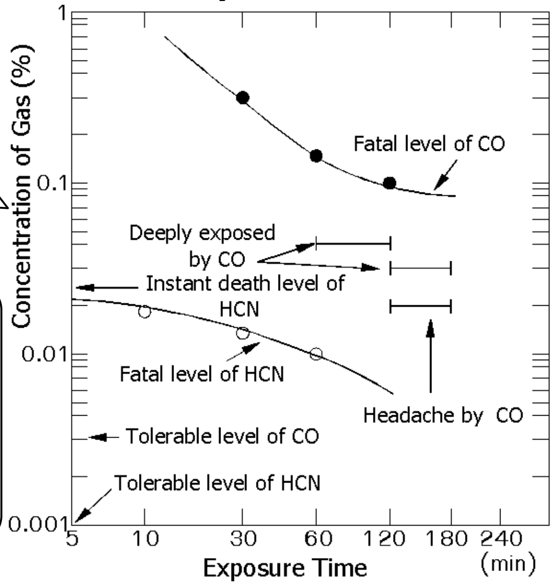
Carbon monoxide (CO) poisoning is th
major cause of death in fires;

- □ 1-hour exposure to 0.2%-CC concentration can put a human to deat as CO-Hb may be more than 60%.

Level of symptoms relate to the rates of CC in hemoglobin (Hb).

- □ 30-40%: badly influenced, i.e. headache vomit, and slow movements.
- □ 40-50%: seriously influenced, i.e consciousness impaired.
- □ 60-70%: fatal, i.e. low blood pressure.

Toxicity of CO and HCN



Tolerable levels are different by types of toxic gases.
i.e. The tolerable level of cyanide nitrogen (HCN)) is 0.001%, much lower than that of carbon monoxide (CO).

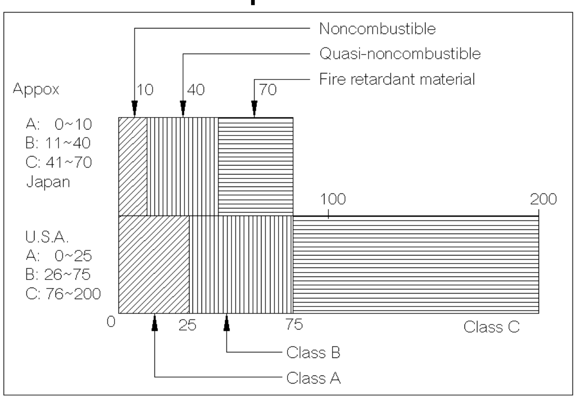
Fire codes in the United States restrict the flame spread and smoke development of noncombustible materials.
Japanese codes further specify limits for physical damage and toxic gas development.
Fire codes in Japan require higher performance for the noncombustible materials.

Classification of Noncombustible Materials

Requirement	Japan			U.S.A.		
	N	Q	F	Class A	Class B	Class C
Heat time (min)	20	10	5	-	-	-
Heat release	X	X	X	-	-	-
Harmful damage	X	X	X	-	-	-
Develop. of toxic gas	X	X	X	-	-	-
Flame spread	-	-	-	0-25	26-75	76-200
Smoke development	X	X	X	0-400	0-400	0-400

Note: N - Noncombustible material, Q - Quasi-noncombustible material, F - Fire retardant material

Flame Spread Index of Noncombustible Materials in Japan and United States



Necessity of Noncombustible Interior Finish

Necessity of Noncombustible Interior Finish in Japan

Classifi-ca tion	Target Building		Required Noncombustible Material			
	Fireproof	Quasi-fireproof	Habitable Room			Corridor/ Aisle
	Total floor Area of 3rd Fl or more (m^2)	Total floor Area of 2nd Fl or higher (m^2)	Wall	Ceiling: 3rd Fl or less	Ceiling: Over 3rd Fl	Wall/ Ceiling
Hotel	300	300	Retardant	Retardant	Quasi	Quasi
Office	500*[1] (1000*[2]) (2000*[3])	Same with fireproof building	ditto	ditto	ditto	ditto
Theater	400 *[4]	100*[4]	ditto	ditto	ditto	ditto
Hospital	300	300	ditto	ditto	ditto	ditto
School	Same with office	Same with office	ditto	ditto	ditto	ditto
Factory	Any	Any	Quasi	Quasi	ditto	ditto
Multi-story housing	300	300	Retardant	Retardant	ditto	ditto
Depart. Store	1000	500	ditto	ditto	ditto	ditto

Legend

(dark) Quasi-noncombustible material

(light) Fire retardant material

Note: 1) *1 is total floor area of a three story building.
2) *2 is total floor area of a two story building.
3) *3 is total floor area of a one story building.
4) *4 is total floor area of a building.
5) Noncombustible interior finish is not necessary where both sprinkler and smoke control systems are provided.
6) The contents of the table are referred to the Building Standard Law.

Both countries regulate the noncombustible interior finish for ceilings and walls of habitable rooms and evacuation routes.
US, further, applies it to floors.

Necessity of Noncombustible Interior Finish in United Sates

Classification	Required Noncombustible Material				
	Habitable Room	Exit		Exit Access	
	Wall/ceiling	Wall/ceiling	Floor	Wall/ceiling	Floor
Hotel	C	A	II	B	II
Office	C	A	II	B	II
Theater (hall)	B	A	II	A	II
Hospital	B	A		B	
School	C	B	II	B	II
Factory	C	B		C	
Multi-story housing	C	A	II	B	II
Department Store	C	A	II	B	II

Legend

(dark) : Class A or Type I

(light) : Class B or Type II

(white) : Class C

Note: 1) The contents of the table refer to the International Building Code (IBC).
2) IBC classifies noncombustible interior finish into:
- Class A, B, and C for wall and ceiling.
- Type I and II for floor.
- Class A and Type I are the least combustible.
3) Grade of noncombustible interior finish required is reduced to a lower grade where a sprinkler system is installed.

Fire Retardant Material in Japan

Fire retardant material is the highest combustible among the three types of noncombustible interior finish materials. It resists the five fire-minutes standard heating without:

- □ Any combustion,
- □ Any generation of smoke or toxic gases,
- □ Any physical damage, such as deformation, cracks, or melting.

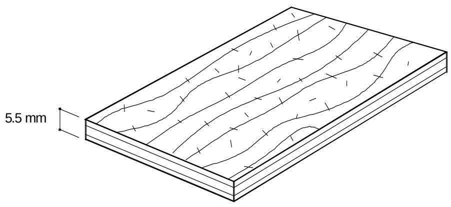
International Standard Organization (ISO) specifies the standard heating with time-temperature curve;

□ $T-T_o=345\log_{10}(8t+1)$

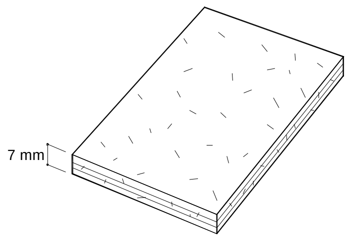
whereby, t is time of heating (minute), T is furnace temperature at the time (degree celsius), T_o is initial furnace temperature (degree celsius).

Sample of Fire Retardant Material

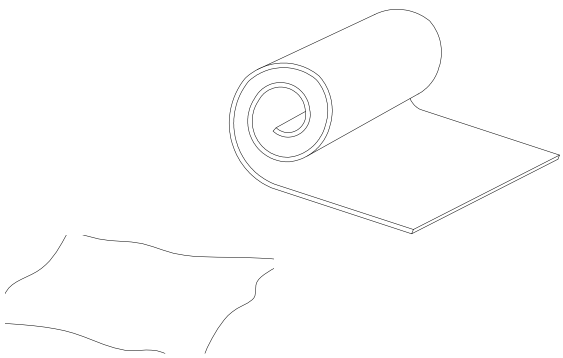
1. Gypsum board (t≥5.5mm)



2. Gypsum board (t≥7mm with covered paper t≤0.5mm)



On the other hand, combustible materials, such as wood, paper and plastics are easily ignited. Petrochemical products are also easily ignited and strongly generate toxic gases and smoke.



When fireproofed, the retardant material includes plywood, fiberboard, and plastics.

Quasi-noncombustible Material in Japan

The quasi-noncombustible material is the middle-graded one among the three types of noncombustible interior finish materials. It resists ten-minutes standard heating without:

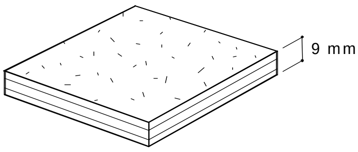
□ Any combustion,

□ Any generation of smoke and toxic gases,

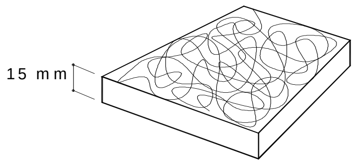
□ Any physical damage, such as deformation, crack, and melting.

Sample of Quasi-noncombustible Material

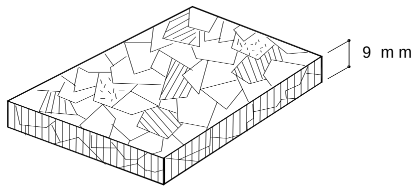
1. Gypsum Board (D≥9mm with covered paper≤0.6mm)



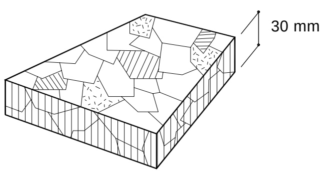
2. Pulp Cement Board (D≥15mm)



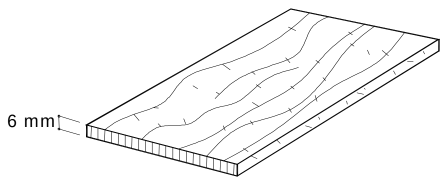
3. Wood Tip Cement Board (D≥9mm)



4. Wood Tip Cement Board (D≥30mm)



5. Pulp Cement Board (D≥6mm)



Noncombustible Material in Japan

The noncombustible material is the least combustible among the three types of noncombustible interior finish materials. It resists twenty-minutes standard heating without;

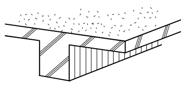
□ Any combustion,

□ Any generation of smoke and toxic gases,

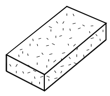
□ Any physical damage, such as deformation, cracking, or melting.

Sample of Noncombustible Material

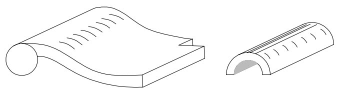
1. Concrete



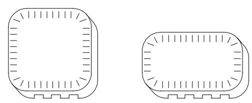
2. Brick



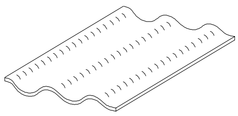
3. Roofing Tile



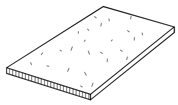
4. Ceramic Tile



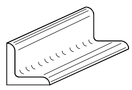
5. Asbestos



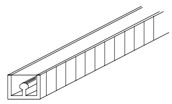
6. Fiber Cement



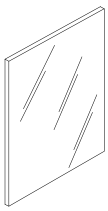
7. Iron (bar, plate, etc.)



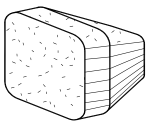
8. Aluminum



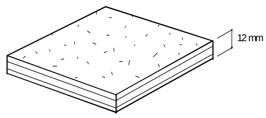
9. Glass



10. Stone, Mortar



10. Gypsum



3 PREVENTION OF FIRE SPREAD

Principle of Fire Separation

Fire separation aims to prevent fire spreading from a room or compartment under fire to other room or compartment and is achieved by the use of fire resistant walls and floors with protection at openings. It is effective for:

□ Minimizing damaged floor area,

□ Safety of evacuation,

□ Safety of fire fighting.

Fire separation is divided into five types;

□ Area separation: subdividing a floor into rooms or compartment within a definite floor area by fire resistant structures.

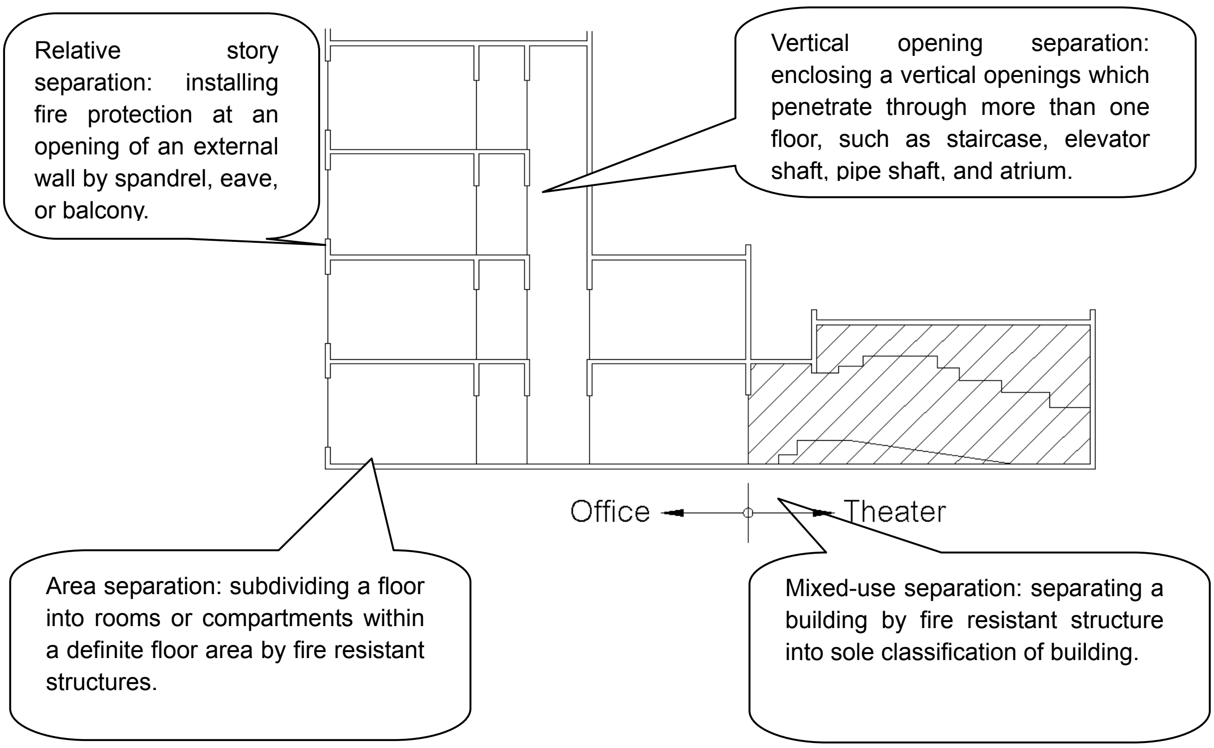
□ Vertical opening separation: enclosing a vertical opening which penetrates through more than one floor, such as staircases, elevator shafts, pipe shafts, and atriums.

□ Relative story separation: installing fire protection at the openings of external wall by the use of a spandrel, eaves, or balcony.

□ Mixed-use separation: separating a building by fire resistant structures into sole classification of building.

□ Separation at incidental use area: enclosing a room or compartment which is a hazardous or important part of a building.

Types of Fire Separation



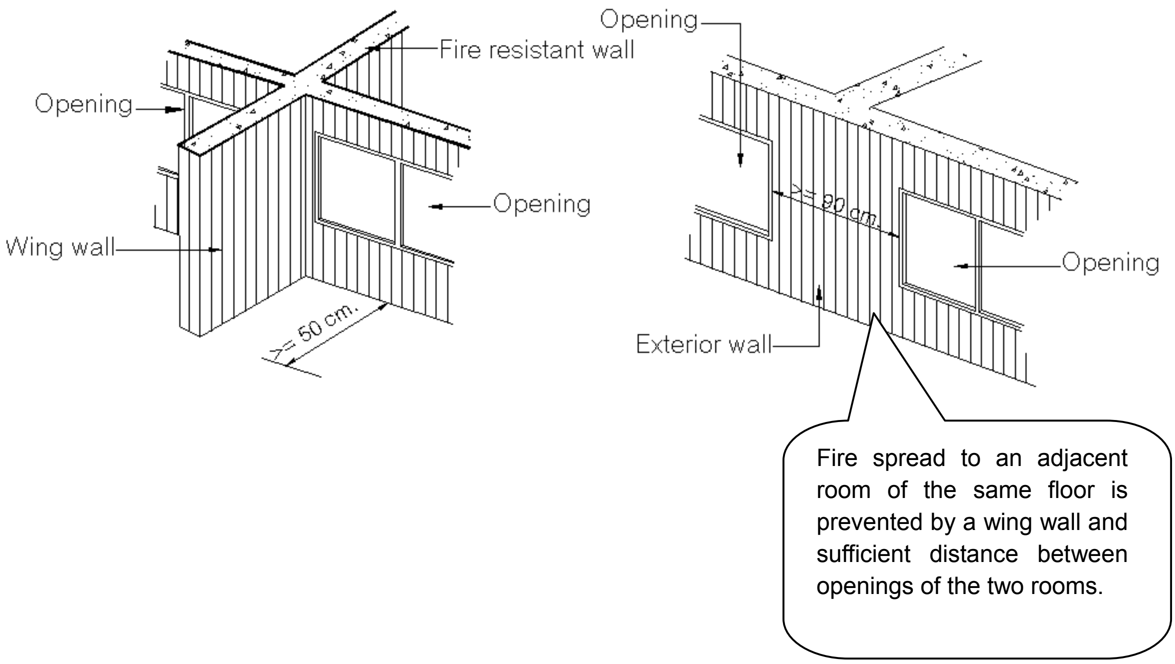
Area Separation

Fire separation is to subdivide a floor into a room or compartment within a particular floor area. It aims to limit damaged floor area and fire spread within the specified floor area. The fire separation is formed by fire resistant walls and floor.

Area Separation in Japan and United States

Fire Code	Building Standard Law (Japan)	International Building Code (United States)
Requirement	The area separation subdivides a floor within each; □ ≦ 1500 m^2 on 10^{th} floor or lower, □ ≦ 100 m^2 on 11^{th} floor or higher. Installation of the sprinkler system doubles the floor area requirement.	IBC has no requirement for area separation. On the other hand, it is substituted by the separation at incidental use areas; □ Electric room, □ Boiler room, □ Cooling machine room, □ Storage, □ Tenant space, others

Fire Protection at Opening of External Wall in Japan



Vertical Opening Separation and Relative Story Separation

The vertical opening separation aims to prevent fire spread through a vertical opening which connects two stories or more. The vertical openings are;

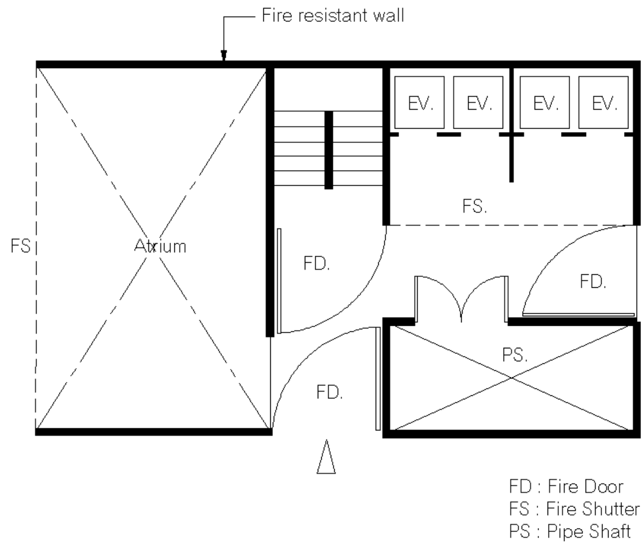
□ Staircases,

□ Elevator shafts,

□ Atriums,

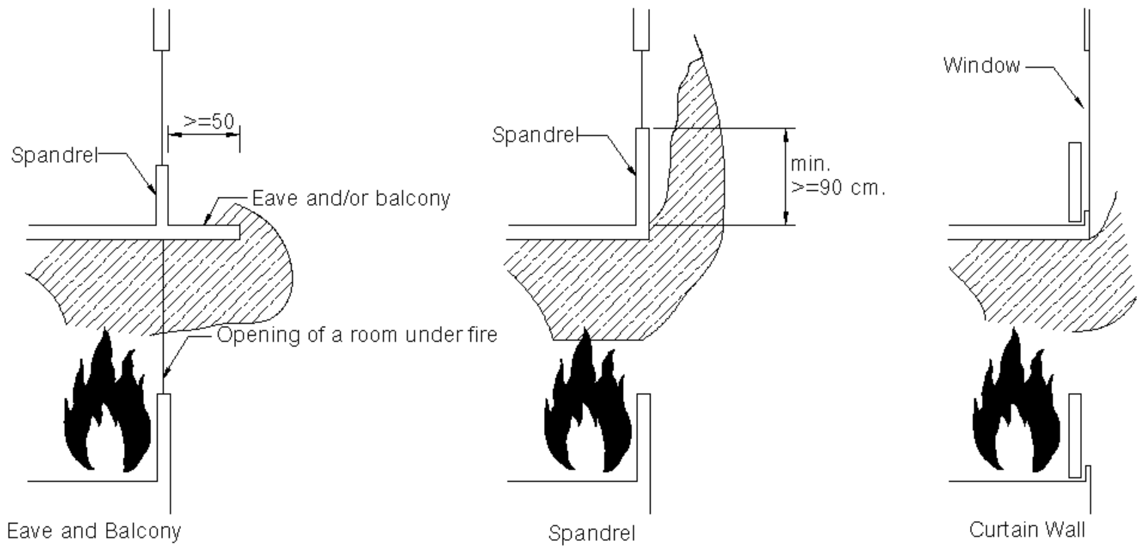
□ Pipe shafts for various service facilities of air conditioning, water supply, sanitary, power supply, and communication.

Vertical Openings to be Separated



The relative story separation aims to prevent the spread of fire to upper and lower floors through openings in external walls.

Openings to be Separated



Mixed-use Separation

Characteristics of buildings are different by:

□ Density and physical conditions of occupants,

□ Fire load and hazardous materials,

□ Operation and management system.

Fire separation by occupancy type aims to:

□ Prevent fire spread within the sole classification of building,

□ Prevent occupants from falling into panic.

Fire-resistance Rating by Occupancy in International Building Code in United States (hour)

	A-1	B	E	F-2	I-1	M	R-1	R-2
A-1		2	2	2	2	2	2	2
B	-		2	2	2	2	2	2
E	-	-		2	2	2	2	2
F-2	-	-	-		2	2	2	2
I-1	-	-	-	-		2	2	2
M	-	-	-	-	-		2	2
R-1	-	-	-	-	-	-		2
R-2	-	-	-	-	-	-	-	

Note:
A-1: Assembly (theaters), B: Business (offices), E: Education (school)s, F-2: Factory, I-1: Institutional (hospitals), M: Mercantile (department stores), R-1: Residential (hotels), R-2: Residential (multi-story housings)

Fire code in US regulates fire-resistance rating of 1 to 4 hours, while the fire-resistance rating for the mixed-use separation is uniformly 1 hour in Japan.

Separation of Incidental Use Areas

Separation of incidental use areas aims to secure safety of:

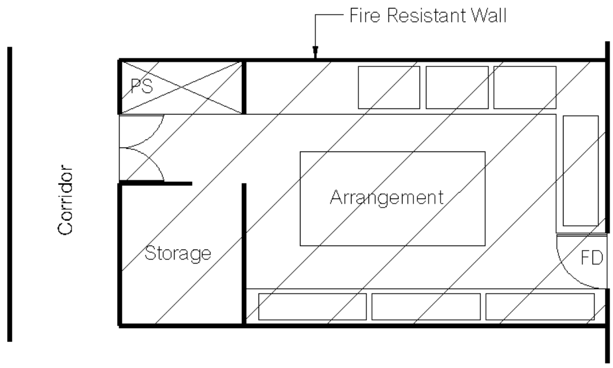
□ Hazardous areas, where fire may rapidly grow,

□ Important areas, which may cause significant damage to the function of a building if a fire breaks out there,

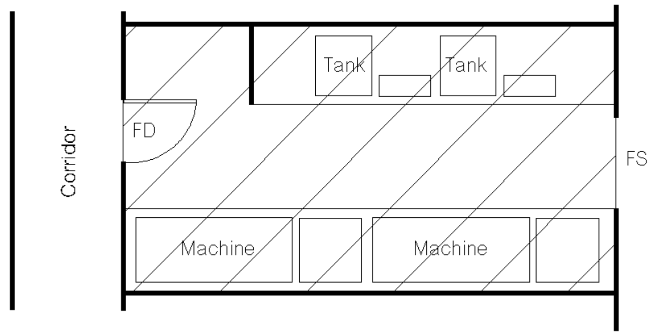
□ Areas occupied by weak persons (e.g., disabled) unable to self-evacuate.

Areas of Incidental Use

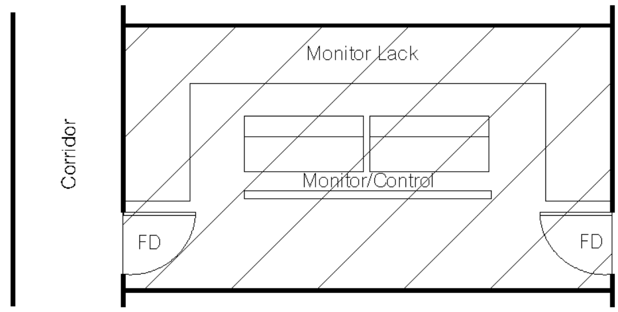
1) Rooms having fire-using equipment, such as kitchen



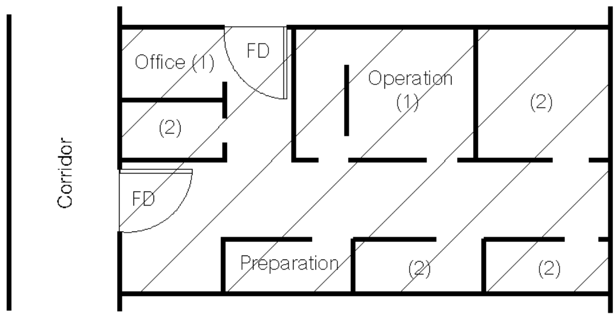
2) Machine room



3) Fire fighting control room



4) Operating room in hospital



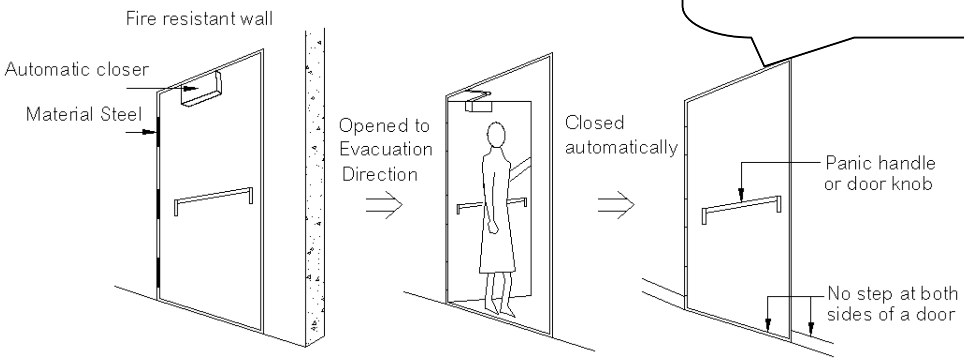
Fire Separation at Openings (1/2)

The purpose of installing fire protection at the openings of fire separation structures is to entirely enclose the fire separation without any openings through which fire can spread to other compartments.

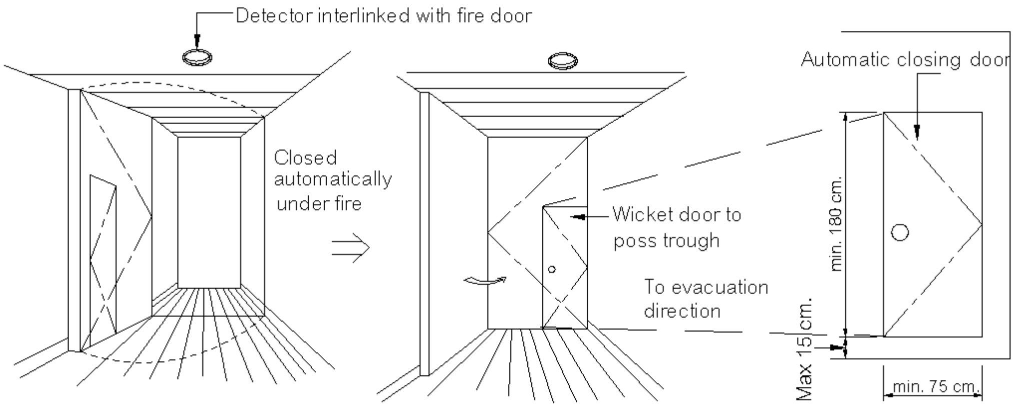
1)Fire door in Japan

□ Standard type: closed at all times.

Fire doors have the advantage of preventing fire spread and providing a path of evacuation at the same time.

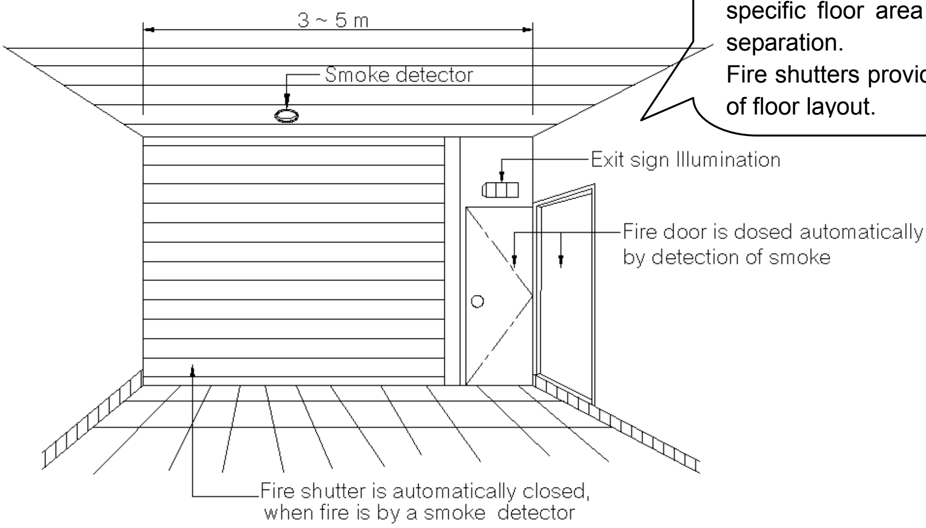


□ Wicket door type: automatically closed by detection of heat or smoke.



2)Fire Shutter in Japan

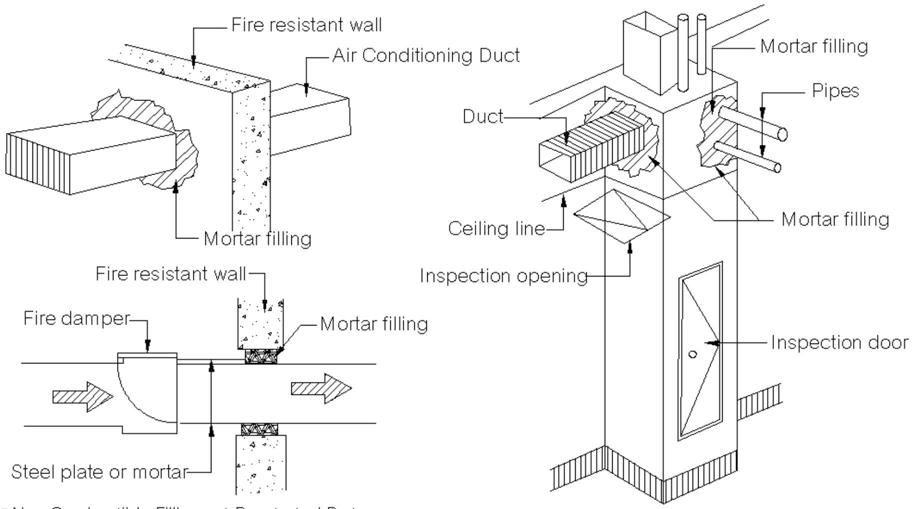
Fire shutters are preferable for rooms larger than the specific floor area of the fire separation.
Fire shutters provide flexibility of floor layout.



Fire Separation at Openings (2/2)

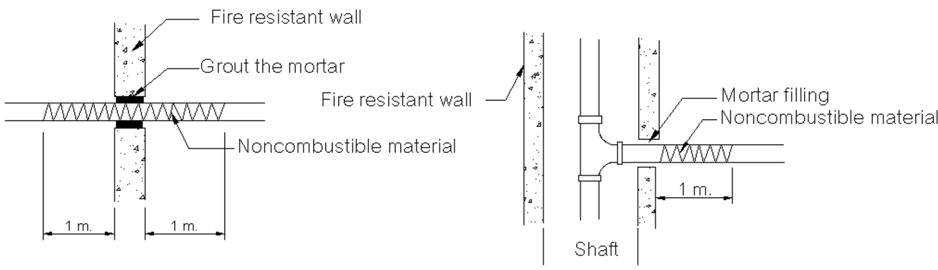
The penetrated parts of fire separation must be protected with noncombustible materials and fire protection equipment.

1)Fire dampers



▯ Non-Combustible Fillings at Penetrated Part

2)Noncombustible fillings at penetrated parts of fire separation



3)Fire protection at openings