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FIRE SAFETY RESEARCH OF HISTORICAL BUILDINGS IN CHINA

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CHINA

ABSTRACT

There are many historical buildings in China with long histories, which are not only valuable cultural assets to China, but also to the international community. In protecting historical buildings in China, fire protection is a major factor. Thus, it is necessary to conduct fire safety research for the protection of historical buildings. In this paper, the structural characteristics and the present fire protection situation of historical buildings in China are introduced, and some typical fire cases are presented. The ancient (and often current) fire protection measures and their drawbacks for historical buildings in China are described. In addition, fire safety research requirements are elaborated, and such further work is considered.

Keywords: Historical buildings, China, fire safety, fire protection.

THE STRUCTURAL CHARACTERISTICS AND FIRE SITUATION OF HISTORICAL BUILDINGS IN CHINA

Historical buildings are generally considered to be the buildings currently conserved with high cultural, historical and artistic values. China has a long history, having historical buildings with a history of up to 7,000 years using independent building systems. There are currently many historical buildings in China and they are widely distributed. Based on incomplete statistics, there are 3,000 historical buildings (excluding historical civilian buildings) in china, including 1,000 historical towers, and 2,000 historical palaces and temples[1]. These buildings are not only valuable culturally to China, but are also an important constituent part of international cultural heritage. For example, the Great Wall, the Peking Imperial Palace, the Dunhuang Grotto, the Qin Emperor Mausoleum and the Peking Man Relics all appear in the list of world cultural heritages.

The structure characteristics

Most historical buildings in China are wood structures, owing to abundant forest resources in ancient China. In contrast, historical buildings in Egypt are typically stone structures (e.g. the pyramids), owing to abundant ore resources. Building materials include wood, stone, pottery including brick and tile, some metals such as copper, etc., but as a whole, most historical buildings in China are wood structures. Furthermore, even for buildings constructed principally of brick or stone or of metal, wood structural frames (beams and columns) and wood components (beams, square wood between two columns) always play essential roles. The typical wood structural frame of historical buildings in China is shown in Figure 1.

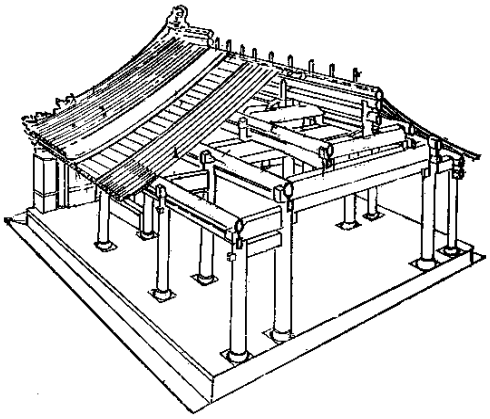


Figure 1: The wood structural frame of historical buildings in China.

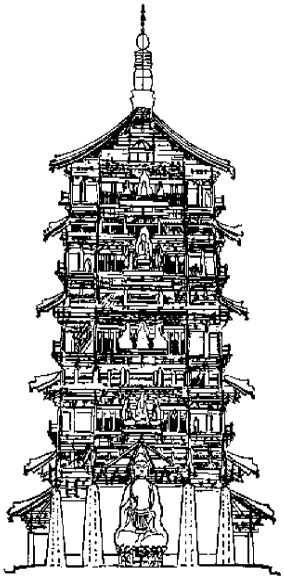


Figure 2: The profile map of Shijia Tower of Fugong Temple in Ying County, Shanxi Province

Historical buildings in China have special structures including huge roofs, grand roof coverings, turn-up and overlapped eaves, gentle roof figures etc. These special structures were used to meet the demand of architectural art and of structure function, such as drainage. Wood structural frames including beams and columns support the roofs in historical buildings in China, while in Western buildings they are often supported by brick walls. The profile map of Shijia Tower of Fugong Temple in Ying County, Shanxi Province, shown in Figure 2, is a practical example of the combination of complex artistic design and a masterly wood structural frame.

The Fire Situation

Fire causes

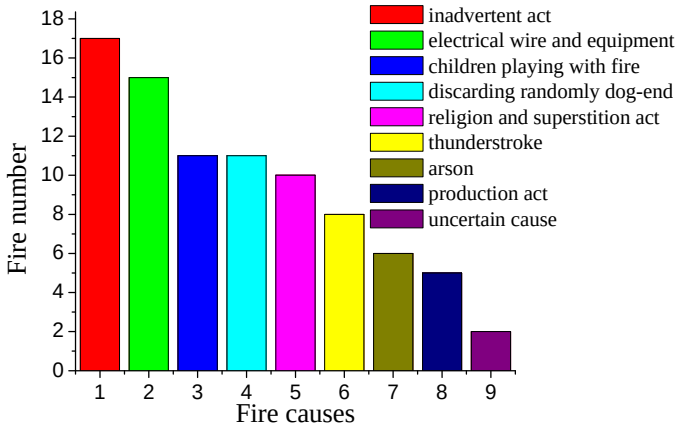


Figure 3: The 85 causes of fire in Chinese historic buildings from 1950 to 1986.

Due to the great combustibility of wood structural frames, fire protection seems to be the most important work in protecting historical buildings in China. In fact, fire has been shown to be the main reason that causes the damage of historical buildings in China. Based on incomplete statistics, there were 85 Chinese historical building fires from 1950 to 1986. These fires were initiated due to different causes, as shown in Figure 3[2]. There were 17 fires caused by inadvertent acts, accounting for 20% of the total fire causes. 15 fires were caused by electrical wire and equipment faults. 11 fires were initiated by children playing with fire, and another 11 fires were due to randomly discarding dog-end. Religious and superstitious acts accounted for 10 fires. 8 fires were caused by lightning strike (thunderstroke). The fires caused by arson and production acts were 6 and 5, respectively. 2 fires arose from uncertain causes.

From the statistical data of fire causes of historical buildings in China, it can be concluded that the fire causes are various and complicated, and none of the causes exceeds the proportion of 20%. The large number of historical building fires in China is partly due to the structure characteristics, and the inner and environmental factors answer for the diversity of the fire causes.

Fire risk analysis

(1) Easily ignited and flashover is produced

The reasons of easy ignition and subsequent occurrence of flashover are listed as:

(a) The main building structure is made up of combustible materials, whose ignition point is usually low.

(b) The building structure is easily combustible, which leads to flashover. Historical buildings in China are built in orderly wood structures so that air is usually abundant. Furthermore, the roof and load-bearing columns are thick and big, and the buildings are difficult to collapse. Therefore, the smoke and heat are hard to dissipate, and the temperature and smoke concentration rises rapidly. Once the critical condition is reached, flashover takes place.

(c) A great number of combustible ornamental materials exist.

(d) Many fire sources are in existence in historical buildings in China.

(e) Lightning strike fires easily take place. Ancient lightning protection techniques were not advanced, and some historical buildings suffer from the danger of lightning strike.

(f) Internal lighting is usually poor. Most of the historical buildings are dark, and are now usually used as tourist venues. So a great mass of electric equipment has been introduced, hidden fire hazards.

(g) Tourists smoke

(h) Some historical buildings are modified as places for production and other activities, which make historical buildings suffer from the danger of fire.

(2) Fire spreads easily.

Though historical buildings in China are mainly monomeric and monolayer buildings, the general plan layout is usually a group arrangement. Therefore, historical buildings are usually destroyed in groups by fire.

(3) Difficultly to extinguish fire

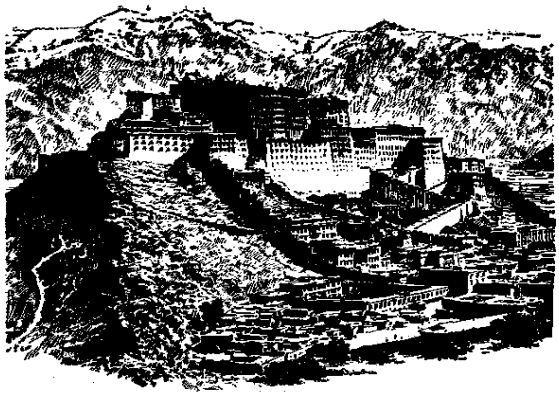
Historical building fires in China are difficult to extinguish due to their special environmental and geographical situations. The main factors are listed as:

(a) Fire engines have difficulty approaching the fire site. Historical buildings in China make full use of the mountains and waters, and are usually built on mountains, making the approach of fire engines difficult.

(b) Most of the historical buildings in China are big and tall. Combustible wood materials are disposed of under big roofs, covered with glass or pottery tiles. These allow fire to take hold in historical buildings, and fire extinguishment is hampered.

(c) Fire equipment and access falls short or fire fighting requirements. There are often no fire roads, fire water supply pipes or fire pools in or near many historical buildings. Thus, fire is often not controlled in the early stages, and as a result large fires take place.

The typical fire cases of historical buildings in China[3]



The Budala Palace fire in Xizang Province

The Budala Palace in Xizang province possesses a long history, and was initially built 7 centuries ago, and afterwards repaired several times. The present design was formed after it was expanded in 1645, shown in Figure 4. There are a great deal of sculptures, murals and command papers, seals, gifts and horizontal inscribed boards of the Ming, Qing Dynasty in Budala Palace. It is one of the key culture protection places of China. In Budala Palace, butter lamps were used in the past, now replaced by electric lamps. However, incorrect installation creates hidden fire problems.

Figure 4: The Budala Palace in Xizang Province.

At 11:55 on June 11 in 1984, two managers suddenly found that black smoke was emanating from the Qiangba Buddhism Hall of Budala Palace. When they fetched the key and opened the door, fire had already spread to the top of the Hall. Unfortunately, there was no water in the fireplugs. So they gave the alarm, while calling people to put out the fire. An 8 m^3 water pond lay in the middle of the Budala Palace, where fire engines could not approach. In this way, fire fighters and people put the fire out using only buckets and washbasins. After the fire was extinguished, the Qiangba Buddhism Hall was badly damaged, and many classics were reduced to ashes.

A post-fire inspection revealed melting marks in the bottom of one pendent lamp in the Qiangba Buddhism Hall. The investigation revealed that incorrect installation caused poor contact, and electric sparks were created when the pendent lamp swayed. In this way, the insulating covers of the pendent lamp combusted, and ignited cloth, wood sticks and branches, etc. initiating the Budala Palace fire.

The Labuleng Temple fire in Gansu Province

The Labuleng Temple is a famous Buddhism scenic spot. It was built in 1709, occupying 1300 mu (1 mu is about 666.7 m^2) with six schools and eight palaces. The Labuleng Temple is famous with grand momentum, being splendid in green and gold. It integrates the building styles of the Han and Zang Nations, and had high historical and artistic value. It is one of the key culture protection places of China. The Big Classics Hall, which is the biggest school in the Labuleng Temple, is made of wood, and the wood is very dry. The butter lamps are always on, and all kinds of cloth goods are hung in the Big Classics Hall, creating many fire hazards.

At 14:10 on April 7 in 1985, the Lama on duty observed that black smoke was coming out from the Big Classics Hall, and found that two bookshelves in the north-east corner of main hall were on fire. He opened the side door attempting to extinguish the fire, but fire grew rapidly due to accelerated air convection. At 14:30, the fire department in Gannan received the alarm call, and dispatched two fire engines and 17 fire fighters who hurried to the fire spot 67 li (1 li is about 0.5 km) away. The fire

department of Ningxia Province also dispatched two fire engines to go to the site from 120 li away, and the fire detachment of Lanzhou reinforced five fire engines from 207 li away. In the dawn of April 8, the fire was extinguished. The fire lasted 16 hours, and the Big Classics Hall was reduced to ashes, shown in Figure 5. Many classics, cultural relics and jewelry crumbled to dust.

The post-fire inspection showed that the fire was initiated when a butter lamp ignited the nearby wood that was stained with oil. The fire spread further, and there was also a fire in other parts of The Labuleng Temple.

Figure 5: The broken scene of the Big Classics Hall of the Labuleng Temple.

The ancient fire protection measures and their drawbacks for historical buildings in China

The ancient people were very afraid of fire, and were continually developing and perfecting fire protection measures. However, with the limitation of ancient science and technology, and the unforeseen present environment which historical buildings now lie in, the ancient fire protection measures are simply inadequate. It is highly necessary to apply the modern developed science and technology techniques in protecting historical buildings in China.

Fire protection layer and fire-resistant covering

Fire protection measures such as fire protection layers for improving fire protection conditions, and increasing fire protection performance of buildings were seen in the ancient book in the era of Spring and Autumn (770 BC). In this book, records were made of removing small buildings and spreading mud on big buildings to protect against fire. The Dadiwan building relic of Qinan in Gansu Province proved that fire-resistant coverings appeared 5,000 years ago, which were slippery, hard and caesious.

It is worth noting that there are no fire protection layers or fire-resistant coverings in most of China's historical buildings. Two reasons account for this situation. Firstly, fire protection layers and fire-resistant coverings destroy the aesthetics of historical buildings. Secondly, fire protection layers and fire-resistant coverings currently conserved have already lost the function of fire protection due to age.

Figure 6: The fire wall in Xidi Village, Yi County, Anhui Province.

Fire wall and fire compartmentation

The ancient fire wall took up a very important role in the ancient fire protection measures. The fire walls differed from common walls, and have four main characteristics. The first was the entire wall was surrounded by the house and heightened above the top of it. The two fore-and-aft walls took on the shape of screens and the two right-and-left walls were the shape of horse heads. The second was the thickness of fire walls was about 20~30 cm, and the fire-resistant time exceeded 6 h. The third was that fire walls did not bear weight, and were independent of the house. The forth was that fire walls formed fire compartmentation in the houses. Once a fire occurred, only one room was affected, even possibly one layer of the room. Fire compartmentation made it impossible for fire to spread to neighbours, or to larger areas. Figure 6 is the fire wall in Xidi Village, Yi County, Anhui Province. The fire walls in historical buildings in China included the Mountain Wall, the Wind-Fire Eave, etc. The Mountain Wall included the Hard Mountain Wall and the Horse-head-shaped Wall.

Fire walls provide the function of fire protection of historical buildings in China only to a certain extent. In the present situation, especially introducing a great mass of electric equipment in historical buildings, it is impossible to avoid fire spreading even if there is a fire wall.

Fire separation and fire roads

Fire separation and fire roads have been long deemed as important technical measures in the layout and construction of a city. The ancient book of Xian Qin[2] summarised the layout of Zhou City (1,027 BC), where there were roads surrounding the inner city, both for security and fire protection, and orderly quadrate city roads. The most famous fire separation and fire roads currently conserved are in the Peking Imperial Palace, shown in Figure 7. But fire walls, fire separation and fire roads only offer a limited function of fire protection of historical buildings in China. In addition, fire separation and fire roads are used for other uses now.

Figure 7: Fire separation and fire road in the Peking Imperial Palace.

Fire fighting water source

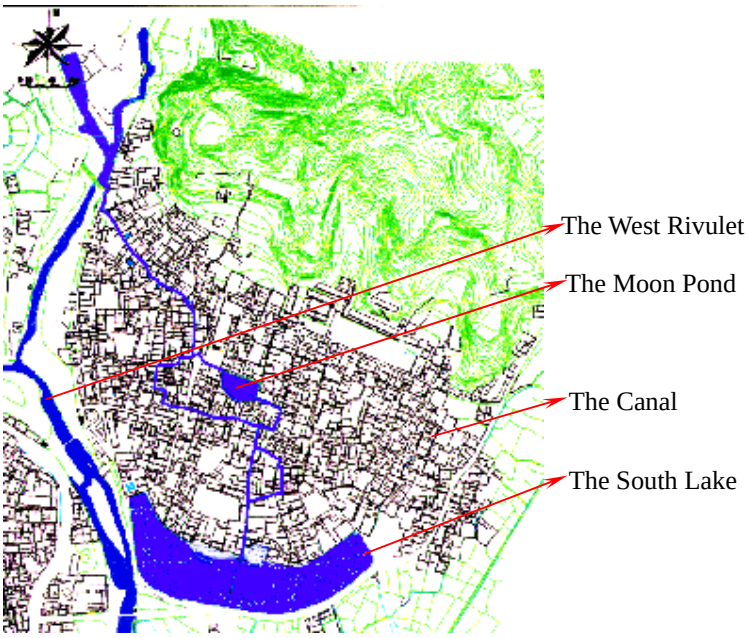


Figure 8: The fire water source in Hong Village, Yi County, Anhui Province.

A water source was always a primary consideration in planning cities, building palaces, government offices, temples and civil houses. Water was not only necessary for drinking and gardens, but also for fire protection. The Yangshao cultural relics, 1,000 of which had been discovered, identify the barbarism of the contemporary society. Most of these relics were built in the side banks, some were built in the junctions of rivers. These choices were not made by chance. In choosing these places, fire protection was an important factor, as well as for the convenience of living, producing, fishing and hunting, and traffic. The typical fire water source was the water source in Hong Village, Yi County, Anhui Province, shown in Figure 8. It was made up of the Moon Pond, the South Lake, the West Rivulet and the Canal for transportation. It not only supplied fire water, but also adjusted the climate and offered the convenience of living and producing. The copper and iron vat in the Peking Imperial Palace, shown in Figure 9, were also fire water sources for the historical buildings far from the original water source.

However, most of present fire water sources in historical buildings in China have already run dry. It is impractical to use these fire water source in protecting historical buildings in China.

Figure 9: The copper and iron vat in the Peking Imperial Palace.

Figure 10: The dragon head with tongue made of iron wire.

Lightning protection measures

The ancient people discovered that lightning strike could also cause fire, so lightning protection measures were invented. The dragon head with a tongue made of iron wire was a lightning conductor, shown in Figure 10. This kind of tongue could be used for lightning protection to some extent. It is obvious that this kind of tongue is not a reliable means to avoid lightning. In fact, fires in historical buildings with these tongues have occurred.

Fire Consciousness

The fire consciousness of the ancient people was also reflected by fetishistic ideas. For example, the horned owl tail and horned owl lip on the fastigium of a house, shown in Figure 11, the well with algae under the roof of the house, shown in Figure 12, and the bead for avoiding fire hanging under the well with algae, shown in Figure 13, etc. The ancient people also built temples for the fire deity, and impetrated fire deity's protection from fire. Figure 14 is the relic of the temple for the fire deity in Dianmen Street in Beijing.

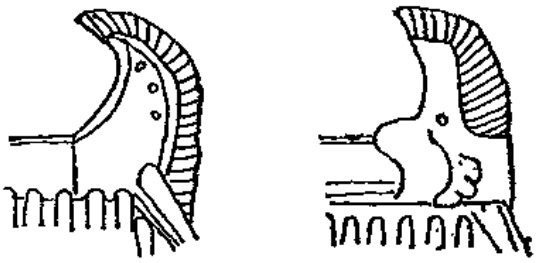


Figure 11: The horned owl tail (left) and horned owl lip (right).

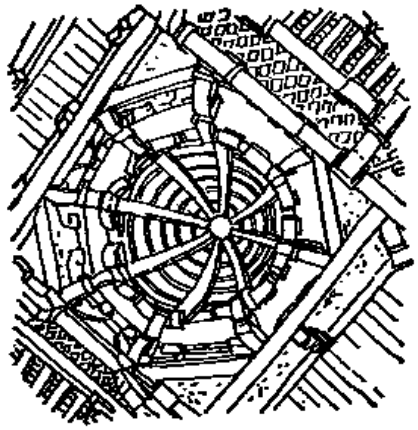


Figure 12: The well with algae.

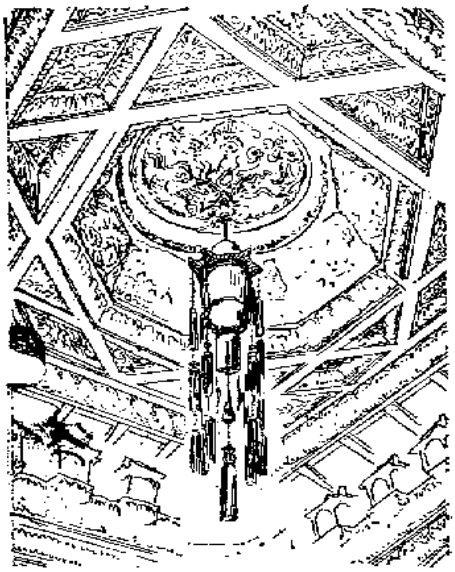


Figure 13: The bead for avoiding fire of Taihe Hall in the Peking imperial Palace

Figure 14: The relics of the temple for the fire deity in Dianmen Street in Beijing.

In fact, these measures were fetishistic measures, and not used for fire protection. They reflect the fire protection dreams of the ancient people.

THE PRESENT FIRE PROTECTION MEASURES AND THEIR DRAWBACKS FOR HISTORICAL BUILDINGS IN CHINA

Special management ordinances

In order to enhance fire protection of historical buildings in China, and to protect them from fire, the Chinese government legislated "the management ordinance of fire protection of historical buildings in China" on March 12 in 1984. The ordinance is composed of six parts. The first is a general rule, in which the objective, applied scope and demand are narrated. The second is organisational and outlines the responsibilities of officers and detailed tasks for fire protection of historical buildings in China. The third outlines pre-fire protection, in which the detailed measures are outlined. The fourth outlines fire extinguishment, in which the stock fire equipment is introduced. The fifth describes rewards and penalties. The sixth is a supplementary article. The legislation enables fire protection of historical buildings in China to have the ordination to comply with.

Fire extinguishment

Chinese fire fighters collect some practical experience in protecting historical buildings in China in the process of fire extinguishment of historical building fires. This is by:

(1) Investigations in ordinary times allow fire fighters to assess the situation, structural form, structural characteristics, and water source of historical buildings, and to prepare and establish the fire emergency plans.

(2) When extinguishing fires, fire fighters can quickly find the ignition source, the fire development tendency, and the level of fire threatening cultural relics; differentiate the fire objects such as monomeric historical buildings, historical towers and historical building groups, and adopt the corresponding measures.

Fire cause investigation

After fire destroys an historical building, the fire cause is investigated in order to avoid the re-occurrence of fire. The procedure and content of fire cause investigation of historical buildings are listed as:

(1) Survey environment, and confirm the ignition range.

(2) Investigate elementarily and confirm the ignition site. In investigating elementarily fire spots, survey the total building in case of neglecting others. This is to limit the investigation range for term-by-term investigation, and to define the investigation emphases.

(3) Investigate term-by-term, and define ignition point.

(4) Investigate special terms, extract material evidence and define fire cause.

Though the present fire protection measures for historical buildings in China involve the full process of fire prevention, fire extinguishment and fire cause investigation, the science and technology content involved in them is limited. These measures are collected mainly from practical experiences, and don't reach the optimal fire protection function. Therefore, it is necessary to develop fire safety research for

the protection of historical buildings in China.

Fire safety research for fire protection of historical buildings in China

Fire protection difficulty increases due to undeveloped ancient science and the modern equipment introduced in historical buildings. In this way, modern developed science and technology is applied to fire protection of historical buildings in China. Certainly, how to combine the characteristics of historical buildings must also be considered. The intrinsic risk of fire cannot be entirely eliminated by installing modern fire protection equipment.

Fire spread and smoke transport in the complex structural figure

Unlike modern buildings, the structural design of historical buildings in China is usually complex. Study on fire spread and smoke transport in the complex structural form can guide fire protection and extinguishment of historical buildings in China. It is well known that spot experiments are impractical. So, numerical modeling, reduced scale modeling experiments and salt water modeling experiments are practical methods. Numerical modeling computation software such as zone modeling software CFAST (Consolidate Fire and Smoke Transport) is applied to predict fire spread and smoke transport. CFAST can be used to compute 12 rooms and to locate ignited materials in rooms, which can be directly applied to study fire spread and smoke transport in historical buildings. The aim of reduced scale modeling experiments is to establish a reduced scale building simulating historical buildings based on the corresponding dimensionless parameters. Experiments in these reduced scale buildings are done to study the law of fire spread and smoke transport, followed by extending to historical buildings to guide fire protection and extinguishment. The aim of salt water modeling experiments is to establish salt water modeling equipment based on the corresponding dimensionless parameters. Experiments are done to study the law of smoke transport in air using the difference in density of salt water and fresh water. In this way, the law of smoke transport in historical buildings is achieved.

The mutual influence between historical building fires and outer fires

Quite a few historical building fires in China are caused by outer fires, so it is necessary to study the mutual influence between historical building fires and outer fires. The historical buildings in cities are usually contiguous to the modern buildings. Therefore, how to avoid the modern building fires to spread to the historical buildings, and build the appropriate fire separation between them, are fire scientific and technological problems. For the historical buildings in a forest, it is necessary to study the mutual relationship between historical building fires and forest fires. Measures such as fire belts may be adopted to prevent the fires spreading between the historical buildings and the forest.

Key techniques

(1) Fire-retardant coating

Fire-retardant coatings can be applied to historical buildings and won't change the colour or scale of combustible and ornamental materials. The new nanometer fire-retardant coatings can be applied in fire

protection of historical buildings by the improvement of techniques.

(2) Fire alarm, control and communication systems

Without affecting the intrinsic completeness and aesthetics of historical buildings, automatic fire alarm, extinguishment and communication system with fire fighters are installed. Such equipment can be installed based on NFPA 914 and the structural characteristics of historical buildings in China. The improved wireless and optical detection techniques can be adopted to reduce the use of electricity and hidden fire hazards. Furthermore, the failure of detection with the traditional detection techniques due to the complex structural design of historical buildings in China should also be avoided.

(3) Developed fire extinguishment technique

Developed fire extinguishment techniques are studied to rapidly put out fires, which will allow various structural components and ornamental materials to retain their original appearance. Therefore, it is necessary to study new fire extinguishing agents and fire extinguishing systems in order to avoid the pollution of traditional fire extinguishing agents that cause the destruction of historical buildings.

(4) Lightning protection technique

Fire cases caused by lightning strike are a common occurrence. How to study developed lightning protection equipment, without affecting the outer figure of historical buildings, using modern lightning protection technique, is a key concern for fire protection of historical buildings.

(5) Fire water supply and road

Considering some historical buildings lie in mountains where water is lacking, modern powerful equipment is applied to install water supply pipes from the bottom to the top of mountains. Without affecting the whole landscape of historical buildings, the fire road is constructed to let fire engines directly enter historical buildings and effectively put out fires.

CONCLUSIONS

Historical buildings in China posses historical, artistic and scientific value, and educational and commemorative meanings. They can reflect the development history of the Chinese Nation and the creativity of people from various eras, and become the non-substitutional practical evidences of human activity. In this paper, the structure characteristics and present fire situations of historical buildings in China were introduced, and some typical fire cases were presented. The ancient, present fire protection measures and their drawbacks for historical buildings in China are described. In addition, fire safety research for fire protection is elaborated.

In protecting historical buildings in China, fire protection is the most important concern. Thus, it is necessary to develop fire safety research for the protection of historical buildings. The fire protection emphases are science and technology factors. Further work should focus on stressing the scientific understanding and applying improved, developed science and technology to fire protection, fire extinguishment and disposal after fire of historical buildings in China. Therefore, governments at different levels should stress the importance of fire protection of historical buildings in China, support fire safety research, and provide appropriate funds to improve the fire protection equipment of historical

buildings in China. The enhancement of fire protection consciousness, especially to great number sof tourists, and monks, also requires further work.

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