FIRE SAFETY OF HERITAGE BUILDINGS WITH TIMBER CONSTRUCTION

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ABSTRACT

Buildings with historic values remain to the present day as living witnesses of the past, and they should be made sustainable by conservation through adaptive re-use and preservation. Owing to the rapid socio-economic development during the past decades, many major cities in the world have been encountering the pressure of new development and redevelopment. This rapid increase in urban regeneration has torn down old fabrics and historic characters of these cities. People are becoming more conscious of historic values and regard these old or ancient buildings as common heritage. While the shared responsibility to safeguard them for our future generation is well recognized by the community, it is onus onto the various building professionals and stakeholders (e.g. building designer, design engineers, fire engineers, and regulators) to preserve them in their full richness of authenticity as far as practicable.

This paper gives a concise definition of heritage buildings, classification of graded historic buildings and general description of conservation principles. When heritage building with timber construction is encountered, it creates substantive difficulty in achieving the current fire safety requirements. As such, Chinese village type house, a representative building type in Hong Kong constructed with timber flooring and timber staircase, is particularly chosen to demonstrate how the current fire safety requirements may be achieved using simple empirical formulae derived from fire engineering approach.

Keywords: Heritage buildings, fire safety, Chinese village type house, fire resisting construction, means of escape, means of access, fire engineering design
1. HERITAGE BUILDING

A heritage building is taken as either a declared monument or a proposed monument defined under the Antiquities and Monuments Ordinance, Cap. 53 (A&MO), a graded historic building accorded by the Antiquities Advisory Board (AAB), a proposed graded historic building or a building to be considered for grading, both of which are recommended by the Antiquities and Monuments Office (AMO).

2. DECLARED MONUMENT OR PROPOSED MONUMENT

Under section 2A of the A&MO, for the purpose of considering whether or not any place, building, site or structure should be declared to be a monument, the Secretary for Development may, after consultation with the AAB, by notice in the Gazette declare it to be a proposed monument, proposed historic building, or proposed archaeological or paleontological site or structure.

Under section 3 of the A&MO, a declared monument means a place, building, site or structure declared to be a monument, historic building or archaeological or paleontological site or structure. Such a declaration shall be made by the Secretary for Development, after consultation with the AAB and with the approval of the Chief Executive in Council, by notice in the Gazette. Once a building has been declared as a monument, the building is legally protected and no person shall undertake building or other works on it without a permit granted by the Secretary for Development. Once declared, section 6 of A&MO prohibits any person to “excavate, carry out building or other works, plant or fell trees or deposit earth or refuse on or in a proposed monument or monument; or to demolish, remove, obstruct, deface or interfere with a proposed monument or monument”, except in accordance with a permit granted by the Secretary for Development.

3. GRADED HISTORIC BUILDINGS

Other than the formal declaration of monument, the AMO has adopted a three-tier grading system to accord buildings of considerable historical and architectural significance. They are classified as:

- **Grade 1**: Buildings of outstanding merit, which every effort should be made to preserve if possible.
- **Grade 2**: Buildings of special merit, efforts should be made to selectively preserve.
- **Grade 3**: Buildings of some merit, preservation in some form would be desirable and alternative means could be considered if preservation is not practicable.

Unlike the declared monuments, a graded historic building, a proposed graded historic building, or a building with historic interests is not legally protected under the A&MO. In March 2009, AMO has provided a list of 1,440 proposed graded buildings, containing 847 buildings under private ownership, of which 584 buildings were previously ungraded. These 584 ungraded buildings may possibly be declared as proposed monuments, subject to negotiation with owners on possible economic incentives or financial subsidies into the possibility of “preservation and redevelopment” option, etc. In case where these buildings undergo alteration and addition works as a result of adaptive re-use, the current building safety requirements should be complied with, or else an equivalent safety standard should be achieved by a balanced approach using performance based design.
4. CONSERVATION PRINCIPLES

It is essential that some fundamental principles guiding the preservation and restoration of heritage buildings should be agreed. Amongst a number of international charters, the Australian ICOMOS Charter or the Burra Charter is a widely recognized document written for the purpose.

Broadly speaking, conservation (保育) is based on a respect for the existing fabric and should involve the least possible physical intervention to the building. It contains all processes of taking care of a place so as to retain its cultural significance. It includes maintenance and may according to circumstances include preservation, restoration, reconstruction and adaption, and will commonly be a blend of more than one of the above mentioned methods. After all, it should not distort the evidence provided by the fabric.

Maintenance (保養) is the continuous protective care of the fabric, contents and setting of a place, and is distinguishable from repair based on the scale of works involved.

Preservation (保存) is to maintain the fabric of a place in its existing state and retard deterioration. Preservation involves minimal works.

Restoration (復修) is to return the existing fabric of a place to a known earlier state by removing accretions or by reassembling existing components without the introduction of new materials.

Reconstruction (重建) is to return a place as nearly as possible to a known state and may be distinguished by the introduction of materials (new or old) into the fabric. It involves demolition and re-building of the entire place.

Repair (修繕) involves restoration and reconstruction and its extent of works is relatively more than that of the maintenance works. Under normal circumstances, repair does not render structural instability of the building or load redistribution within the structure. For extensive repair which involves structure of the building, it is duly regarded as structural repair.

Adaptation (適用) is to modify a place to suit proposed compatible use (相容的使用). It involves no change to culturally significant fabric, changes which are substantially reversible, or changes which incur a minimal impact to the place. Adaptation, or adaptive re-use, has a broad definition which embraces both “the functional upgrading works without changing the existing (or original) use” and “the provision of a different use” of heritage building. First of all, the term “adaptive re-use” is to be separated into two terms, namely “adaptive” and “re-use”. The term “re-use” implies a “change of use”, and the term “adaptive” is considered as enriching the meaning of sustaining a place while not letting it progressively deteriorates. The term “re-use” should be regarded as neutral. The consequence of “adaptive re-use” is Revitalization (活化), which should always be construed as compatible use of the heritage building. The aim of conservation is to enable people to interpret the history and original use of the place, and “adaptive re-use” is an effective means.

Buildings with historic values are emblems of the past; thus, protection of heritage buildings becomes as important as protection of occupants. Under no circumstances should the historic values be compromised with inappropriate adaptive re-use, which may incur substantial alteration and addition (A&A) works to the heritage buildings. While its historic and aesthetic values may be preserved economically via adaptive re-use, an appropriate adaptive re-use could be devised through appraisal (particularly structural appraisal) such that A&A works to the
heritage building could be made minimal with the least disturbance. Fire engineering approach, a readily performance-based design tool, is regarded as probably the only solution in resolving fire safety issues with minimal disturbance to the heritage buildings so as to render them sustainable in their full authenticity for our next generations.

5. FIRE RESISTING CONSTRUCTION REQUIREMENTS

The fundamental principle for Fire Resisting Construction (FRC) is to ensure the structure could resist the action of fire for a period called Fire Resistance Period (FRP) so as to maintain structural stability during fire escape and fire-fighting / rescue.

In Hong Kong, the FRC requirements were first referenced from the London County Council (LCC) By-laws 1952, 1964 and subsequent amendments as stipulated in the Buildings Ordinance (BO) 1955. The FRC requirements were then stipulated in the Building (Construction) Regulations [B(C)R] 1976 and B(C)R 1985. As these requirements were removed in B(C)R 1990, they were put in the FRC Code 1989 and subsequent FRC Code 1996.

According to FRC Code 1996 every building should be compartmented by walls and floors to inhibit the spread of fire. In the FRC Code, the minimum FRP is 1 hour for compartment volume not exceeding 28,000 m³.

In clause 13.1 of FRC Code, it cites that ‘All roofs, together with the members forming the roof structure, should be constructed of non-combustible materials.’

In the glossary of FRC Code, ‘element of construction’ is construed as any floor, beam, column or hanger, any load-bearing wall or load-carrying member other than a member forming the roof or part of a roof; or any required staircase including the landings and supports thereto. The timber cockloft floor, which supports floor load, is considered as an element of construction and should have an FRP of 1 hour minimum.

The glossary of the FRC Code also cites that a ‘required staircase’ is an access staircase in a fire-fighting and rescue stairway or a staircase required for means of escape in case of fire. In clause 11.4 of the FRC Code, each element of construction of a required staircase including the landings and supports enclosed within walls having the required FRP need not have an FRP but must be non-combustible.

In Hong Kong, the FRP requirements were first put in a separated section in Part XIII of the B(C)R 1956, in which the 1/2 hour FRC requirements on timber flooring and timber element of construction was referred to Schedule VI of LCC By-Laws 1952. The FRP requirements were later incorporated in Part XVI of B(C)R 1976 and B(C)R 1985. The B(C)R 1976 contains the provision in clause 184 which implies that each element of construction of any building not exceeding 3 storeys can have a 1/2 hour FRP. These FRP requirements were put into the FRC Code 1989, which is now superseded by the FRC Code 1996. It should also worth noting that the application of 1/2 hour FRP was retained in the B(C)R until the FRC Code 1989 was implemented in 1990.

The FRC Code 1989 was intended for modern buildings of large and complex compartment. The minimum FRP was 1 hour which corresponded to compartment volume not exceeding 28,000 m³ for uses other than bulk storage and warehouse. Normally, for a traditional 2-storey
Chinese village type house, the total compartment volume of the whole building from ground level to the underside of the roof is only about 140 m³, which is far less than the limit of 28,000 m³.

It is logical, therefore, to consider incorporating the 1/2 hour FRP requirement for the elements of construction in these small-scale heritage buildings such as the traditional Chinese village type houses. Reference is made to BS 9999:2008, in which the 1/2 hour FRP requirement is explicitly stipulated.

To demonstrate how the current fire safety requirements may be achieved for buildings with timber construction, a traditional Chinese village type house which is a representative building type constructed with timber flooring and timber staircase, is particularly chosen for the purpose.

Traditional Chinese village type houses in Hong Kong are 2-storey domestic buildings. They are commonly built of stone/brick masonry walls with timber cockloft, timber floors and timber roof rafters and battens supporting non-combustible clay tiles.

To simply comply with the prescriptive FRC Code appears impossible. Firstly, the roof structure constructed of timber materials is readily combustible. Secondly, the timber floor planking (an element of construction) cannot sustain 1 hour FRP. For the open timber staircase, it would jeopardize the historic fabric if enclosed within a fire rated wall shaft.

The aspect of combustible timber material is still unresolved. It poses much difficulty to upgrade these buildings to meet current building standard without greatly devastating the historic fabric and materials. In terms of heritage conservation, such attempt would become meaningless if any upgrading will blight the originality of the building. Adaptive re-use involving change of use for these Chinese village type houses is possible but the extent of adaptive re-use should be carefully assessed.

6. FIRE RESISTING CONSTRUCTION OF TIMBER ROOF

In accordance with clause 13.1 of the FRC Code, it is cited that ‘All roofs, together with the members forming the roof structure, should be constructed of non-combustible materials.’

The objective of the clause is worth opening for further discussion. If there is concern on the structural stability of the timber roof rafters and battens under fire exposure, it is viable to prove that the timber element possesses certain FRP and would not collapse within certain period of time.

If there is concern about the spread of flame under fire exposure, the timber surface can be applied with coats of fire retardant material. It is generally accepted that the spread of flame could be controlled by applying fire retardant paints on the timber surface every 2-3 years subject to the severity of abrasion by wear and tear on the timber surface. Such fire retardant paints are usually transparent and would not impair the historic fabrics. However, it is advisable, before any such upgrading is carried out, the AMO should be consulted for the effect on the existing finish.

In this respect, the clause may need to be reviewed with clear objectives.
7. FIRE RESISTING CONSTRUCTION OF TIMBER COCKLOFT FLOOR

Timber floor is considered as element of construction and it can possess certain FRP, hence the structure can resist the action of fire within a certain period.

When timber is exposed to fire, its surface would be charred. A char layer and a pyrolysis zone will be formed which serves as an effective insulator to prevent further heat penetration into the core of timber. By adopting an acceptable charring rate of the timber as stipulated in BS 5268:4-1:1978, the structural capacity of the remaining core section can be calculated.

Therefore, with respect to the timber joist, the core portion left unburnt can provide certain structural capacity subject to structural justification.

However, the timber plank, which is not thick enough to provide a residual thickness to achieve certain structural capacity when exposed to fire, should be protected with fire rated board at the soffit. As for the top of the timber floor planking, it can be protected with removable fire rated floor tiles. (Figure 1 refers). However, for the purpose of exposing the historic timber surface, one may argue not to lay fire rated tiles on top of the timber planking. This may be achieved by using a fire engineering approach to substantiate the non-provision of the fire rated tiles on top of the timber planking (Figure 2 refers).

Figure 1
According to the FRC Code, the timber staircase should be enclosed within a fire rated enclosure shaft. This would significantly affect the appearance of the historic fabric of the building. Fire engineering design approach will be adopted to demonstrate that the unprotected open timber staircase is structurally stable over certain FRP during fire escape and fire-fighting / rescue purposes.

9. MEANS OF ESCAPE

It was first stated in regulation 37(a) of the Building (Planning) Regulations 1956 that “every building shall be provided with such means of escape in case of fire as may be required by the intended use of a building”. In Building (Planning) Regulations 1966 and 1976, they gave similar provisions. In regulation 41 of the Building (Planning) Regulations 1990, provisions for the Means of Escape (MOE) are stipulated. The first Code of Practice for the guidance of authorized architects in the preparation of plans for design of taller and larger-compartment buildings was published in December 1959. Subsequent revisions were published in 1968, 1975 and 1986 respectively.

The Codes of Practice for the Provision of Means of Escape in Case of Fire (MOE code) 1996 was based on the type of use, the population and the travel distance. Alternative approach such as fire engineering approach may be used when it is necessary to justify the adequacy of MOE for old buildings with layout plan different to those required today. Fundamental requirements of means of escape should be worked out for adaptive re-use of and A&A to heritage buildings.

In traditional Chinese village type house, the stair may be unprotected and the whole interior could be regarded as one common compartment (including all upper floors). The concept of staircase with closed door and compartment walls of non-combustible material was introduced in the BO 1935. The stair riser and tread of 7” (175mm) and 9” (225mm) were also introduced at that time. Fire escape was first made as a requirement in BO 1935 (section 45) for any floor greater than 35 feet above ground. Section 43(5) of BO 1935 required the staircase of a building...
be upgraded for BA’s approval when conversion (A&A) is involved. This implies that older stairs of steep angle of climb were considered a deficiency in the building.

10. MEANS OF ACCESS FOR FIRE FIGHTING AND RESCUE

In parallel with the provision of the Means of Access for Firefighting and Rescue (MOA) code in 1996, there were provisions already stipulated in the regulations 41A, 41B, 41C and 41D of Building (Planning) Regulations 1990. No mention of this aspect was found in Building (Planning) Regulations 1984 or before.

The first MOA code was published in 1989 and subsequently revised in 1995 and 2004. In the Practice Note for Authorized Persons and Registered Structural Engineers and Registered Geotechnical Engineers PNAP-APP 136 (or formerly called PNAP 288), it provides recommendations to comply with the requirements of MOA by providing enhanced fire service installations (FSI). In general, fundamental requirements on MOA should be justified for adaptive re-use of and A&A to heritage buildings.

Please refer to Appendix I for the evolution of the Buildings Ordinance, the Fire Resisting Construction provisions, the Means of Escape provisions and the Means of Access for Firefighting and Rescue provisions respectively.

11. EXAMPLE OF FIRE SAFETY COMPLIANCE

A 2-storey masonry-timber Chinese village type house constructed in 1930 was specially chosen as a particular example for demonstration purpose. The house was originally used for domestic purpose whereas the adaptive re-use proposes a change of use as office. The building plans are attached in Appendix II for reference. One MOE staircase is required to serve the 1/F as stipulated in clause 9.2 (a) of the MOE Code. The condition of the existing timber staircase is sound whereas its width, 1.0 m, is slightly less than the required minimum width of 1.05 m with a protective barrier of 1.1 m high. The tread and riser of the staircase are slightly less than the current requirements. Since the existing staircase is constructed of timber material and minimal disturbance is imposed on the building fabric, every endeavour would be made to justify the timber staircase as a required staircase using fire engineering approach.
12. TYPICAL NON-COMPLIANCE WITH THE CURRENT FIRE SAFETY REQUIREMENTS

As far as the fire safety is concerned, the following three aspects under the jurisdiction of Buildings Department should be mentioned:

a) Fire resisting construction (FRC)
b) Means of escape in case of fire
c) Means of access for fire fighting and rescue (MOA)

Typical non-compliances are noted as follows:

- Insufficient FRP for timber flooring – min. 1 hour FRP as given in Table 2 of FRC Code.
- Combustible timber staircase – Clause 11.4 of FRC Code refers.
- Insufficient staircase width – Table 2 of MOE Code & Clause 20 of MOA Code
- Substandard tread and riser dimensions of staircase – Clause 17.2 of MOE Code & Clause 20 of MOA Code

While the extant 1 hour FRP requirement have excluded the use of timber structure, the 1/2 hour FRP requirement with fire resisting construction details as stipulated in B(C)R 1976 may be seriously considered as a valid reference standard in view of the relatively small size and height of the Chinese village type house.

Usually, these traditional Chinese village type houses would have a total GFA less than 230 m². As stipulated in the Fire Service Installations and Equipment (FSI) Code, sprinkler protection is not required for a building where the total GFA is less than 230 m². Nevertheless, sprinkler installation, addition of smoke vent and reduced water tank size for fire hydrant / hose reel and/or sprinkler system(s), etc., may be proposed as appropriate in accordance with the result of the performance-based design assessment.

13. FIRE ENGINEERING DESIGN APPROACH

Performance-based fire engineering design approach is used to demonstrate an equivalent fire safety for the heritage building.

It is essential that the stability of these structures with timber construction has to be demonstrated with adequate structural capacity under certain FRP prior to justifying the adequacy in Means of Escape and Means of Access for Firefighting and Rescue.

In general, the following basic assumptions are made in the fire engineering design:

- The stability of the structure can be justified under fire exposure.
- Fire growth rate is assumed medium for office use.
- The timber staircase is used for means of escape.
- Smoke detectors will be installed in the house.
- 450 mm smoke curtain will be installed at the soffit of 1st floor.
- Fire sprinklers will NOT be installed under the roof and the soffit of first floor.
14. **ASPECTS OF CONCERN IN STRUCTURAL STABILITY UNDER FIRE EXPOSURE**

**Timber charring rate**
Timber would char when exposed to fire. The timber beneath the char layer and the pyrolysis zone does not lose significant strength because the thermal conductivity is low. These characteristics enable it to predict the structural performance in a fire resistance test.

**Timber strength**
It was stipulated in B(C)R 1976 that the permissible design strength is 5.5 MPa for certain ungraded softwood. This value is considered safe in most design.

**FRP for timber element**
The charring layer thicknesses for 30 minutes and 60 minutes are measured from fire tests. Please refer to BS 5268: Part 4.1: 1978.

15. **ASPECTS OF CONCERN IN MEANS OF ESCAPE AND MEANS OF ACCESS**

**ASET**
ASET is the period of time available for safe egress of occupants from the premises on fire. The usual practice is to demonstrate that the fire will be brought under control before toxic conditions or excessive temperatures are reached, i.e. tenable condition.

**RSET**
RSET is the time required for safe egress of occupants from the premises on fire. It comprises the time for detection, alarm rising, pre-movement and travel for evacuation. For instance, the tread and riser dimensions of the staircase, human behaviour, number of occupants, number of exit door, exit door width, exit route width, type of detection system, etc are considered.

**Factors affecting ASET**

**Smoke layer height**
It is normally assumed that the smoke clear height is set at 2m above the finished floor level.

**Maximum gas temperature under tenable condition**
In the event of an outbreak of fire, the maximum temperatures of the hot smoke layer should be assessed such that the occupants could escape under tenable condition.

**Radiation level**
When occupants pass close to a fire or under a hot smoke layer, they may be exposed to radiant heat. Tenability limit for exposure of skin to radiant heat has been proposed as an exposure resulting in severe pain to unprotected skin.

**Visibility level**
In the event of an outbreak of fire, the degree of visibility measured in terms of the density of smoke particles/flame droplets suspended in the air should be assessed such that the tenable condition for occupants to escape can be verified.
Toxicity level
Untenability can result from hypoxia at a concentration of oxygen (O₂) of 13 percent or lower. Extended exposure to concentration of O₂ below 10 percent can result in brain damage. In the event of an outbreak of fire, the level of toxic gas such as CO should be assessed such that the tenable condition occupants to escape can be verified. Other gas species including hydrogen cyanide (HCN) (e.g. acrylic, sofa), hydrogen chloride (HCL) (e.g. paraffin, sofa) and various smoke organic irritants should also be controlled. For their threshold limits, please refer to CIBSE Guide E.

Criteria for structural stability under fire exposure

<table>
<thead>
<tr>
<th>Aspects of concern</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber charring rate</td>
<td>Table 1 – Notional rate of charring for calculation of residual section</td>
</tr>
<tr>
<td>Species</td>
<td>Charring in 30 minutes (mm)</td>
</tr>
<tr>
<td>a) All structural species listed in Appendix A of BS 5268-2:1989 except those noted in items b) and c) below</td>
<td>20</td>
</tr>
<tr>
<td>b) Western red cedar</td>
<td>25</td>
</tr>
<tr>
<td>c) Hardwoods having a nominal density not less than 650 kg/m³ at 18% moisture content</td>
<td>15</td>
</tr>
</tbody>
</table>

Extract from Table 1 of BS 5268-4.1:1978

<table>
<thead>
<tr>
<th>Timber strength</th>
<th>Allowable strength = 5.5 MPa (ungraded softwood) ~ 7.0 MPa. Refer to then prevailing B(C)R 1976 or BS 5268.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP for timber element</td>
<td>1/2 hour FRP for small floor area of building with timber construction.</td>
</tr>
</tbody>
</table>
### Criteria for life safety of occupants

<table>
<thead>
<tr>
<th>Criteria</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ASET</td>
<td>Smoke layer height: -&lt;br&gt;At least 2m AFFL (above finished floor level)</td>
</tr>
<tr>
<td></td>
<td>Maximum gas temperature under tenable condition: -&lt;br&gt;&lt;br&gt;<strong>Table 10.6 Critical temperature for different exposure conditions</strong>&lt;br&gt;&lt;br&gt;</td>
</tr>
<tr>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>Radiation</td>
<td>Severe skin pain</td>
</tr>
<tr>
<td>Conduction (metal) (1 second)</td>
<td>Skin burns</td>
</tr>
<tr>
<td>Convection (30 minutes)</td>
<td>Hyperthermia</td>
</tr>
<tr>
<td>Convection (&lt;5 minutes)</td>
<td>Skin/lungs burns by hot gases</td>
</tr>
<tr>
<td>Convection (&lt;1 minute)</td>
<td>Skin/lungs burns by hot gases</td>
</tr>
</tbody>
</table>

† black-body: 2.5 kW/m²

Extract from CIBSE Guide E

<table>
<thead>
<tr>
<th>Criteria</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RSET</td>
<td>T_{detection} + T_{alarm} + T_{pre-movement} (recognition and response)(refer to PD7974-6) + T_{travel} + Safety Margin</td>
</tr>
<tr>
<td></td>
<td>T_{detection} : time from fire ignition to detection, dependent on type, sensitivity and installation location of detector, fire growth and fire type. (Use computer program to calculate T_{detection})</td>
</tr>
<tr>
<td></td>
<td>T_{alarm} : time from detection to notification of occupants, usually close to zero</td>
</tr>
<tr>
<td></td>
<td>T_{pre-movement} : delay time prior to initiation of occupant movement, critical part in fire engineering approach.</td>
</tr>
<tr>
<td></td>
<td>T_{travel} : time for occupant to travel to safe place, e.g. protected lobby and exit staircase</td>
</tr>
<tr>
<td></td>
<td>Safety Margin : usually presumed as 0.5 times T_{travel} for this particular small size heritage building, which is considered adequate</td>
</tr>
</tbody>
</table>
Empirical formulae commonly used in fire engineering design with worked solutions to the above-mentioned example (in bracket)

<table>
<thead>
<tr>
<th>Timber charring rate</th>
<th>( x \text{ (mm)} = [0.5\text{−}0.83] t \text{ (min)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bullet ) Normally, the timber floor joists can be unprotected if it is thick enough such that the residual core section can yield structural capacity.</td>
</tr>
<tr>
<td></td>
<td>( \bullet ) Normally, the timber floor plank should be protected with fire-rated board at the soffit only.</td>
</tr>
</tbody>
</table>

ASET Use FPETOOL program
- Detector’s response time index = 50 (ms){0.5}, fast
- Spacing of smoke detector = 3m x 4m
- No sprinkler is installed
(The FPETOOL gives ASET = 60 seconds)

RSET
- Use FPETOOL to calculate \( T_{\text{detection}} \)
  (= 0 second, as the building layout is simple and provides good visual and audio openness to the occupants)
- Assume \( T_{\text{alarm}} \)
  (= 0 second)
- Assess \( T_{\text{pre-movement}} \) using PD7974-6
  (= 30 seconds for ‘awake and familiar situation’)
- Use FPETOOL to calculate \( T_{\text{travel}} \)
  (= 10 seconds)
- Assume time for Safety Margin = 0.5 times \( T_{\text{travel}} \)
  (or 5 seconds)

\( \text{RSET} = 0 + 30 + 10 + 5 = 45 \text{ seconds} < \text{ASET} \)
### Observations

<table>
<thead>
<tr>
<th>Timber charring rate</th>
<th>For 100x200 timber joist with charring layer of 25mm, it is found structurally adequate subject to 1/2 hour FRP. For china fir, the charring rate would normally be ( x \text{ (mm)} = [0.76] \text{ t (min)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSET Safety Margin</td>
<td>Some may assume an over-conservative Safety Margin by multiplying 1.5 to ( [T_{\text{detection}} + T_{\text{alarm}} + T_{\text{pre-movement}} + T_{\text{travel}}] )</td>
</tr>
<tr>
<td>Smoke layer height</td>
<td>As the house is very small, all occupants would have escaped before the smoke layer descends down to 2m AFFL</td>
</tr>
<tr>
<td>Maximum gas temperature under tenable condition</td>
<td>Since the house is small, all occupants would be clear from the hot smoke layer and the maximum gas temperature in this case could be set at 185 °C.</td>
</tr>
<tr>
<td>Radiation level</td>
<td>Since the fire growth rate is medium for office use, and the occupants would have escaped from the fire origin; it is unlikely that occupants would suffer from heat flux exceeding 2.5 KW/m².</td>
</tr>
<tr>
<td>Visibility level for tenable condition</td>
<td>Refer to typical Fire Dynamic formulae to assess visibility. As the occupants are clear from the smoke layer, there is no visibility problem in this case.</td>
</tr>
<tr>
<td>Exposure limit of toxicity for tenable condition</td>
<td>It is reasonably to assume that toxic gas would not exist in the cool lower layer, which is used as means of escape.</td>
</tr>
</tbody>
</table>

### 16. LIMITATIONS OF FPETOOL SOFTWARE

The software was developed by the Building and Fire Research Laboratory at the National Institute for Standards and Technology in USA with support from the General Services Administration. **FPETOOL** is a collection of engineering calculations that provide the user with tools to estimate a number of conditions resulting from fire in compartments. There are many elements in the software, and one of them is the software, and one of them is the CFAST (a two-layer zone model software), which stimulates a fire in a single room containing a simple two zone model (i.e. a hot upper layer and a cool lower layer) that can simulate the effects of pre- and post-flashover fires in a room. The effects of sprinklers, operation of heat or smoke detectors, ventilation options are available, along with predictions of smoke properties (oxygen, carbon dioxide, carbon monoxide concentrations) as well as heat transfer through walls and ceilings, etc.

### 17. SOFTWARE ASSUMPTIONS

The software has its own inherent assumptions and the user should be aware of the built-in parameters, for example:-

i) the nominal spacing of detectors = 3m x 4m; hence, the minimum size of the compartment room should not be less than 3m x 4m;

ii) the roof should be flat and horizontal and hence pitched roof is not allowed. However, for traditional Chinese village type houses with timber pitched roof, an equivalent flat
and horizontal roof with adjusted headroom can be adopted;

iii) effects of specific location of opening in the room cannot be modeled;

iv) Response Time Index (RTI) for fast response sprinkler is usually taken as $50 \text{ (ms)}^{0.5}$ whereas normal type sprinkler is $200 \text{ (ms)}^{0.5}$.

The scope of use of FPETOOL is limited and the input parameters and the results should be assessed and endorsed by a qualified and competent fire engineering professional.

18. CONCLUSION

The industry poses strong aspiration in adopting a delicate approach between a sound heritage policy and reasonable safety standards. The heritage value should be reflected in the first instance by means of management plan to arrive at a reasonable safety standard, rather than disturbing and impairing the historic fabric of heritage buildings only for the sake of compliance with the prescriptive building safety requirements.

To arrive at a sympathetic solution, the regulator will play a pivotal role to adopt a balanced approach to achieve building safety requirements using performance based design while the heritage value is maintained. Under the current circumstances, it is apparent that the performance based approach with compensatory measures is the sympathetic solution.

Management Plan, which generally involves an actual population rather than theoretical population based on occupant factor justifying an equivalent safety standard for means of escape and means of access for fire fighting and rescue, is complicated and its enforceability should be further studied. It requires substantive support from the relevant Control Authorities and even enforcement through legislation, and should be carefully devised. Hence, it will not be elaborated in this paper.

Having taken into account the current status in the fire safety control of small sized heritage buildings, some recommendations are proposed below for deliberation and implementation:

1) the use of simple empirical formulae with justifications may be used rather than the sophisticated Computational Fluid Dynamics (CFD) modeling;

2) the regulator should be conversant with knowledge of fire science and fire engineering principle, as well as the application of simple empirical formulae with an understanding of the assumptions and limitations behind;

3) acceptance criteria should be stipulated for the regulator in vetting these empirical formulae for simple building layout such as these small-sized Chinese village type houses with open layout plan;

4) the parameters adopted in these empirical formulae should be proposed and endorsed by a competent and qualified personnel in the fire discipline;

5) the then prevailing 1/2 hour FRP fire safety requirements on timber elements as stipulated in B(C)R 1976 may be duly considered as acceptance criteria on a case-by-case basis for change of use in small-sized heritage buildings constructed with timber floors and timber staircase; and

6) Management Plan, which generally involves the actual population justifying an equivalent safety standard for means of escape and means of access for fire fighting and rescue, should be elaborated in terms of the feasibility of implementation and enforcement.
REFERENCES


ACKNOWLEDGMENT

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BACKGROUND OF THE AUTHORS

Ir Professor Paul Pang is the Chairman of the Fire Division; a Council Member; a Founding Member of the Fire Discipline Advisory Panel; the Immediate Past Chairman of the Structural Discipline Advisory Panel; and a Past Chairman of the Joint Structural Division of the HKIE. Ir Professor Pang serves the HKSAR Government as an Assistant Director of the Buildings Department, responsible for the control and enforcement policies of existing private buildings in Hong Kong. He is also the Chairman of the Technical Committees on the Codes of Practice for the Structural Use of Steel and Concrete under the Buildings Department. He acquires vast experience including planning, design, construction, forensic and control of building and civil engineering works through his 36 years of professional career. Currently, he is an adjunct professor at the Hong Kong Polytechnic University and the Hong Kong City University.

Ir Dr W T Chan is a Committee Member of the Fire Division of the HKIE. He is the Vice President of the Hong Kong Institute of Steel Construction (HKISC) and the Chairman of the Jointing, Welding and Cold-Formed Steel Group. Dr Chan works in the HKSAR Government as a Senior Structural Engineer in the Buildings Department, and serves as the Secretary to the Technical Committee on the Code of Practice for the Structural Use of Steel under the Buildings Department. His interests cover welding of structural steel, fire engineering, façade engineering and the use of high strength steel.
A. Evolution of Buildings Ordinance (BO) in Hong Kong

<table>
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<tr>
<th>Period</th>
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<td>1955</td>
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<td>1990-todate</td>
<td>1990</td>
<td>repealed</td>
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* LCC By-Laws 1938 (for architects) –repealed in 1969
  LCC By-Laws 1952 and subsequent amendments (specially permitted when a structural engineer is employed)

B. Evolution of Fire Resisting Construction Code

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# Particular provisions in BO were relevant.
## C. Evolution of Means of Escape Code

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# Particular provisions in BO were relevant.

## D. Evolution of Means of Access for fire-fighting and Rescue Code

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# Particular provisions in BO were relevant.
Building Plans for the example

- Masonry brick wall
- Timber element

1/F Plan

A

B

3600

6250

5000

1000