FIRE SAFETY ENGINEERING AND POTENTIAL APPLICATION OF FIRE MODELS

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ABSTRACT

With the rapid development of construction projects with new architectural design, 'engineering performance-based fire codes' are widely used in many countries overseas. This leads to the new subject discipline 'Fire Safety Engineering (FSE)', in contrast to the traditional fire engineering dealing with prescriptive codes. FSE is a high-level subject, transferring fire science to practical use to provide safety. This gives an opportunity of linking 'upstream' research to 'mid stream', 'downstream' and the practical world.

New architectural features such as those for green or sustainable buildings might have difficulties in following prescriptive fire codes. Examples include the internal voids, double-skin façades and others. As a result, fire safety engineering has to be applied for designing fire safety provisions such as passive building constructions.

In this paper, the new subject area fire safety engineering will be introduced. In carrying out hazard assessment, fire models might have to be used. Potential application of those fire models will also be discussed. How fire engineering approach was applied to safety provisions in Hong Kong since 1998 will be described. Basically, three levels of studies had been adopted for over 80 new projects or renovations of the existing buildings. Further, education and training required are pointed out.

Keywords: fire safety engineering, fire models, performance-based fire codes

1. INTRODUCTION

Fire safety in both new buildings with architectural features [e.g. 1] and existing buildings is a key issue. Apart from several big accidental fires occurred in Hong Kong since 1996 [2], the number of fires other than those caused by accidents over the world (such as terrorist attack fire in World Trade Centre and arson fire in Southern Korea underground railway) appears to be increasing. People are worrying about the hidden problem on fire safety and queried whether they are sufficiently protected while staying indoor, including building and transport vehicles.

Fire codes in most countries or cities are basically prescriptive [3-6]. The codes were developed decades ago with some slight modifications. They are demonstrated to be good for fire safety provisions in buildings which are relatively simple and not for complex usage. Modern architectural design features such as those [7] listed in Fig. 1 have given new challenges to fire safety design. These include:

- Environmental friendly buildings to provide more natural ventilation.
- Use of new materials.
- Changes in the style of living.

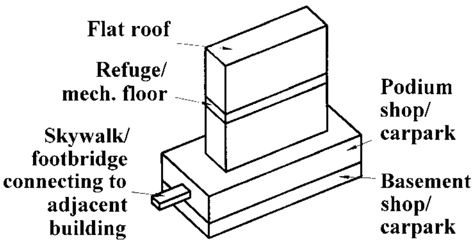
Obviously, fire codes, even those by NFPA [e.g. 8], cannot be updated so rapidly to cope with the changes. This is particularly obvious for buildings of special hazards requiring individual design considerations, leading to Engineering Performance-Based Fire Codes (EPBFC) [8-14]. Therefore, scientific research for fire safety provision must be enhanced, leading to the new subject discipline of Fire Safety Engineering (FSE). This is different from the traditional fire engineering based on prescriptive codes. There, routine 'cut and paste' designs, say on fires services installations, are commonly carried out.

There had been numerous arguments on providing fire safety for some new buildings in the past few years [15]. The hidden adverse effects on fire hazard for the following architectural features were discussed:

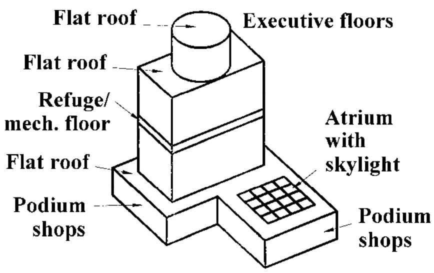
- Internal building voids [16] might give smoke and even flame spreading rapidly due to enclosure effects.
- Double-skin façade might give faster vertical fire spreading rate.
- Excessive natural ventilation design with air flow induced by wind on windloading and smoke spreading.
- Using good thermal insulation envelope materials might set off flashover rapidly as

demonstrated by several incidents of burning the entire double-deck bus within 15 minutes.

These features might not satisfy the prescriptive fire safety codes, especially in countries where codes were not updated regularly. Supporting research and development works on fire safety engineering must be carried out before specifying the safety requirements.



(a) Type I Buildings



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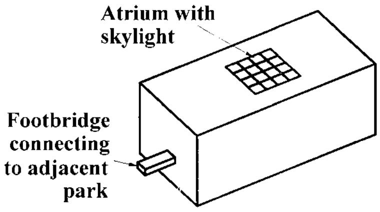

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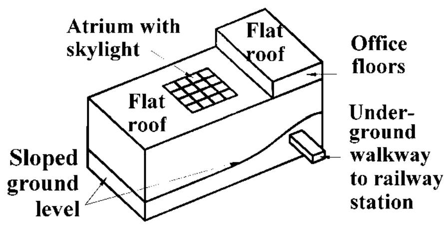

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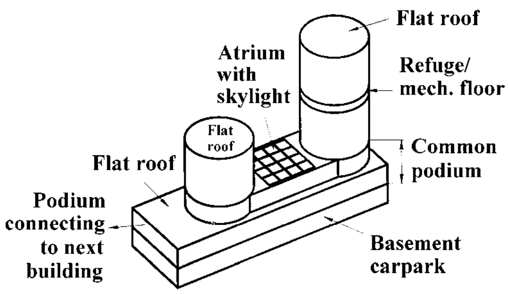
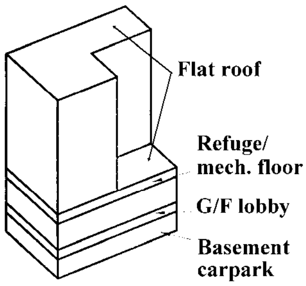
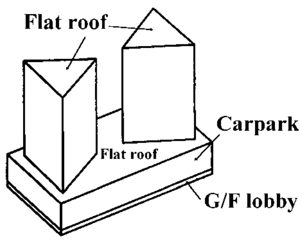


(e) Type V Buildings



(f) Type VI Buildings



(g) Type VII Buildings

Fig. 1: Modern buildings in Hong Kong

2. CODE REVIEW: HONG KONG AS AN EXAMPLE

To provide fire safety, passive building constructions and active fire protection systems have to be provided. These are regarded as hardware provisions. In addition, software provisions on fire safety management [17] should be worked out. The total fire safety concept is the same in everywhere, though fine tuning of some parts might be necessary. Taking Hong Kong as an example, fire codes are basically prescriptive [4-6] following those developed decades ago, though with some slight modifications. Codes on passive building construction (PBC) are:

- Code of Practice for Provisions of Means of Access for Firefighting and Rescue Purposes (MoA code) [3]
- Code of Practice for Fire Resisting Construction (FRC code) [4]
- Code of Practice for Provisions of Means of Escape in case of Fire and Allied Requirements (MoE code) [5]

Code on active fire protection system or fire services installation (FSI) is:

- Code of Practice for Minimum Fire Service Installations and Equipment and Inspection and Testing and Maintenance of Installations and Equipment (FSI code) [6]

These codes are demonstrated to be good for fire safety provisions in buildings which are relatively simple and not for complex usage. Those modern architectural design features have given new challenges to fire safety design. Therefore, fire codes should be updated in order to cope with those rapid changes. This is particularly obvious for buildings of special hazards requiring individual design considerations. But doing this without strong scientific fire research for local safety provision is impossible.

Local approval of fire safety design and inspection of the building upon completion are held responsible by the Buildings Department (BD) and Fire Services Department (FSD). Normally, the building design shall be submitted to the BD to check against all fire aspects for approval; and the requirement and installation of fire protection system shall be determined by the FSD. A pictorial presentation of the decision-making process is shown in Fig. 2.

Note that there are no EPBFC in Hong Kong yet. But for those buildings having difficulties to satisfy the prescriptive fire codes on passive building construction, a 'fire engineering approach (FEA)' [18] will be accepted by the government Buildings Department (BD) since 1998. In applying FEA, a fire safety evaluation report has to be submitted to the Fire Safety Committee (FSC) under BD for consideration. This gives an opportunity of applying fire safety engineering.

3. FIRE SAFETY ENGINEERING

There are many definitions of Fire Safety Engineering (FSE). For example, in technical report BS ISO/TR 13387-1 (1999) [10] in UK:

- FSE can mean many things to many people. At one level, it can mean the calculation of pipe sizes for sprinkler systems or the calculation of the structural response of a building element, such as a beam or a column, from a knowledge of the material properties at elevated temperatures, the temperatures they achieve, the loads acting, and so on.
- At another level, requiring the use of integrated computer programmes, it can mean evaluating the life safety consequences of a specified fire, which involves defining the context, defining the scenario and calculating the hazard.
- At a more strategic level, FSE can mean a package of measures (methodology, calculation tools and data) which has the objective of reducing the potential for injury, single deaths and multiple deaths in and nearby the building to an acceptable level.

FSE is commonly applied for those buildings where prescriptive fire codes cannot be followed. An obvious example is to provide sprinkler at a high headroom atrium in Hong Kong. This might give adverse effects such as steam production and smoke logging. Different standard methods are specified in assessing those designs. Examples are BS ISO/TR 13387-1:1999 in UK [10], American approaches such as SFPE guide [e.g. 12] and Japanese approaches, say on assessing a building type [e.g. 11]. As drafted by the International Code Council (ICC), there are three parts [19]:

- Documentation.
- Design levels.
- Topic specific intent.

The following items should be judged, if necessary:

- Fire safety objectives and acceptance criteria.
- Design parameters.
- Characterization of buildings and its occupants.

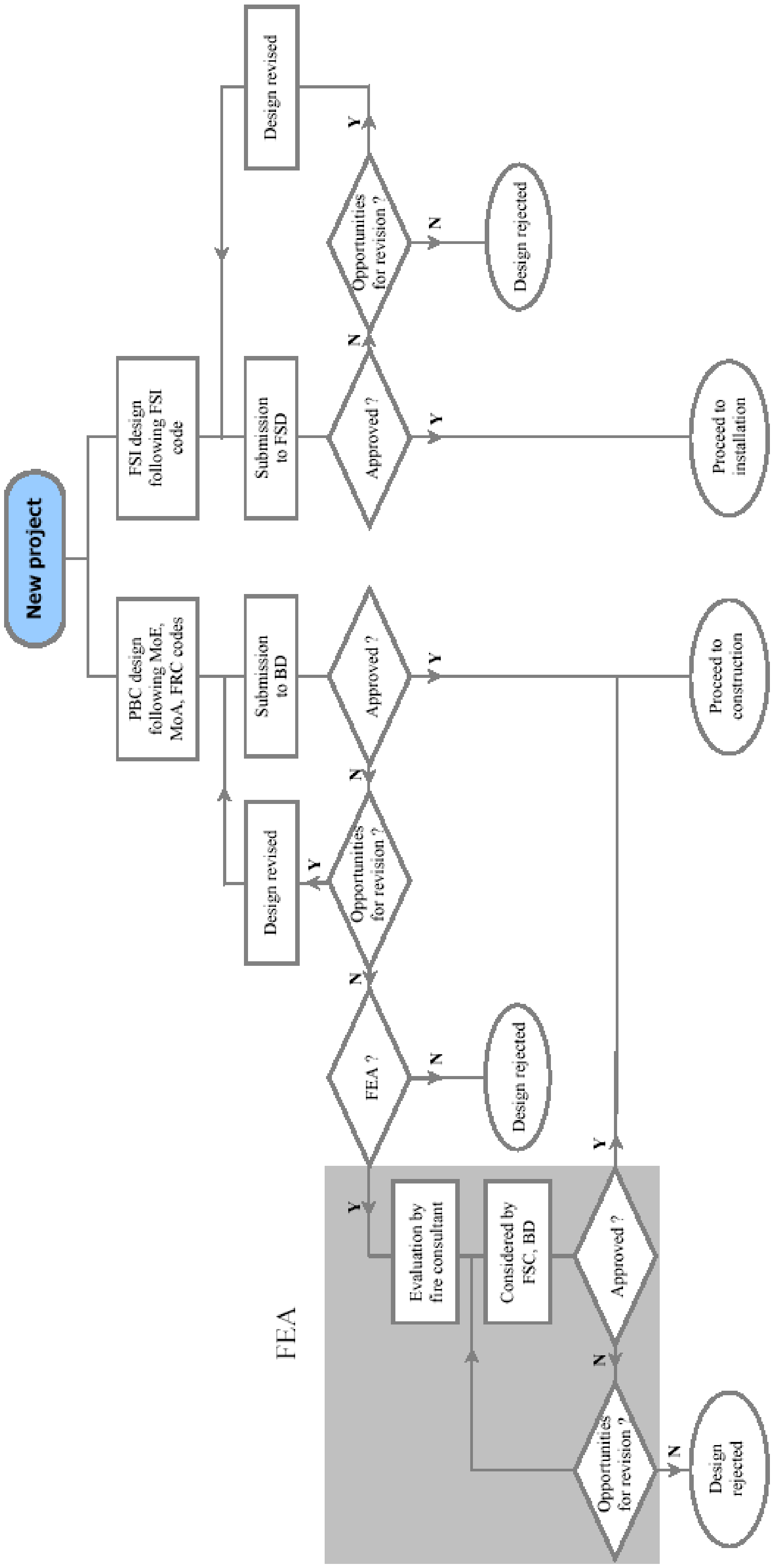


Fig. 2: Process for approving fire safety designs

- Identification of potential fire hazard scenarios and their possible consequences.
- Assessment against the safety criteria.

Hong Kong is now working on EPBFC, might be ready several years later. But basically, only those deviated from the existing prescriptive codes would be assessed in FEA. Therefore, the objective of the FSE approach is quite clear, i.e. based on existing prescriptive codes.

Similar to what have been summarized by Lillicrap [20], the following questions are usually raised:

- What level of fire safety is acceptable?
- What are the precise features and dimensions of the building?
- What factors limit possible solutions?
- What are the main hazards and consequences?
- What fire safety measures are going to be in place?
- What scenarios are going to be studied?
- What method of analysis is going to be used?

Knowledge of fire science and engineering was applied together with practical experience under local conditions. Mathematical fire models [e.g. 21-26], either zone models or field models, were commonly used to analyze potential fire scenarios. Full-scale burning tests [e.g. 27], scale models studies and site measurements on evacuation pattern [e.g. 28] are required when necessary.

4. IMPORTANCE OF HEAT RELEASE RATE

A common question always asked in a fire hazard is:

How big is a fire?

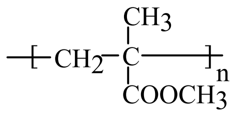
To answer that, the heat release rate has to be assessed. A database on heat release rate [29,30] should be developed for determining a design fire. This is one of the most important parameters that can be used to characterize an unwanted fire by providing:

- An indication of the size of the fire.
- The rate of fire growth, and consequently the release of smoke and toxic gases.
- The time available for escape or suppression.
- The types of suppressive action that are likely to be effective.
- Other attributes that define the fire hazard.
- Whether flashover would occur.

Different values were used by the designers in the past in Hong Kong:

- Terminal hall: up to 7 MW
- Shopping mall: 5 MW
- Atrium: up to 7 MW
- Train compartment: 1 MW

Some values were accepted by the Government, but some were rejected. This is due to the lack of a database for local products. But most important, heat release rate is taken as the input parameter for fire model. As in a liquid pool fire, it is obvious that turbulence, intermediate combustion chemistry and thermal radiation have to be included instantaneously. Taking poly(methyl methacrylate) PMMA as an example, the chemical structure is:



The chemical reactions of PMMA burning are very complex possible intermediate reactions [31]:

- Thermal degradation
- Thermal oxidative degradation
- Decomposition of monomer MMA
- Methane combustion
- Methanol combustion
- Formaldehyde oxidation
- Acetylene combustion

Taking methane combustion [32] as an example, there are 77 intermediate reactions as shown in Table 1!

These phenomena cannot be modeled accurately in the coming ten years. Therefore, heat release rate of burning objects must be measured and taken as the parameter in fire hazard assessment. Previously, that was measured by the mass-loss-rate method. Now, oxygen consumption rate method based on the assumption that burning 1 kg of oxygen would give 13.1 MJ of heat is used [29]. An exhaust hood with a fan-duct system is required, with an accurate oxygen analyzer for measuring the amount of oxygen consumed.

5. POTENTIAL APPLICATION OF FIRE MODELS

Knowledge of fire science and engineering has to be applied in assessing the fire safety designs. Mathematical fire models [21-26] are useful in the analysis of consequences of fire hazard scenarios. Instead of carrying out physical tests, full-size or scale models, they are useful in EPBFC. There are arguments and debates on using fire models and EPBFC is not equivalent to fire models. If the predicted results are not verified scientifically, say by full-scale burning test [27], the process would appear as a 'curve-fitting exercise'. Since the intermediate chemistry in burning materials, mixing of air and fuel due to turbulence and thermal radiation are difficult to model in a fire, the heat release rate is taken as the input parameter in most mathematical fire models. Full-scale burning tests should be carried out to establish a heat release rate database on local materials and consumable products.

Table 1: Methane oxidation due to Glarborg et al. [1992]

$H + O_2 = O + OH$ (1)	$CH_2(S) + O_2 \longrightarrow CO + OH + H$ (40)
$O + H_2 = H + OH$ (2)	$CH_2(S) + CO_2 \longrightarrow CH_2O + CO$ (41)
$OH + H_2 = H_2O + H$ (3)	$CH + H = C + H_2$ (42)
$OH + OH = H_2O + O$ (4)	$CH + O \longrightarrow CO + H$ (43)
$H + OH + M \longrightarrow H_2O + M$ (5)	$CH + OH \longrightarrow HCO + H$ (44)
$H + O_2 + M \longrightarrow HO_2 + M$ (6)	$CH + OH = C + H_2O$ (45)
$HO_2 + H \longrightarrow OH + OH$ (7)	$CH + O_2 \longrightarrow HCO + O$ (46)
$HO_2 + OH \longrightarrow H_2O + O_2$ (8)	$CH + H_2O \longrightarrow CH_2O + H$ (47)
$CO + OH = CO_2 + H$ (9)	$CH + CO_2 \longrightarrow HCO + CO$ (48)
$CH_4 + H = CH_3 + H_2$ (10)	$C + OH \longrightarrow CO + H$ (49)
$CH_4 + O \longrightarrow CH_3 + OH$ (11)	$C + O_2 \longrightarrow CO + O$ (50)
$CH_4 + OH = CH_3 + H_2O$ (12)	$NH + H \longrightarrow N + H_2$ (51)
$CH_3 + H \longrightarrow CH_4$ (13)	$NH + O \longrightarrow NO + H$ (52)
$CH_3 + H = CH_2 + H_2$ (14)	$NH + O \longrightarrow N + OH$ (53)
$CH_3 + H = CH_2(S) + H_2$ (15)	$NH + NO = N_2O + H$ (54)
$CH_3 + O \longrightarrow CH_2O + H$ (16)	$N + OH \longrightarrow NO + H$ (55)
$CH_3 + OH = CH_2 + H_2O$ (17)	$N + O_2 \longrightarrow NO + O$ (56)
$CH_3 + OH = CH_2(S) + H_2O$ (18)	$N + NO = N_2 + O$ (57)
$CH_3 + OH = CH_2OH + H$ (19)	$O + N_2 + M \longrightarrow N_2O + M$ (58)
$CH_3 + O_2 \longrightarrow CH_2OH + O$ (20)	$N_2O + H \longrightarrow N_2 + OH$ (59)
$CH_3 + HO_2 \longrightarrow CH_2OH + OH$ (21)	$HCN + O \longrightarrow NCO + H$ (60)
$CH_3 + HCO \longrightarrow CH_4 + CO$ (22)	$HCN + O \longrightarrow NH + CO$ (61)
$CH_2OH + M \longrightarrow CH_2O + H + M$ (23)	$HCN + OH \longrightarrow CN + H_2O$ (62)
$CH_2OH + O_2 \longrightarrow CH_2O + HO_2$ (24)	$HCN + OH \longrightarrow NCO + H_2$ (63)
$CH_2O + H \longrightarrow HCO + H_2$ (25)	$CN + OH \longrightarrow NCO + H$ (64)
$CH_2O + OH \longrightarrow HCO + H_2O$ (26)	$CN + O2 \longrightarrow NCO + O$ (65)
$HCO + M \longrightarrow CO + H + M$ (27)	$NCO + H \longrightarrow NH + CO$ (66)
$HCO + H \longrightarrow CO + H_2$ (28)	$NCO + OH \longrightarrow NO + CO + H$ (67)
$HCO + OH \longrightarrow CO + H_2O$ (29)	$NCO + NO \longrightarrow N_2O + CO$ (68)
$HCO + O_2 \longrightarrow CO + HO_2$ (30)	$CH + N_2 \longrightarrow HCN + N$ (69)
$CH_2 + H + M \longrightarrow CH_3 + M$ (31)	$C + N_2 \longrightarrow CN + N$ (70)
$CH_2 + H = CH + H_2$ (32)	$CH_2 + NO \longrightarrow NCO + H_2$ (71)
$CH_2 + O \longrightarrow CO + H + H$ (33)	$CH_2(S) + NO \longrightarrow OH + HCN$ (72)
$CH_2 + O \longrightarrow CO + H_2$ (34)	$CH + NO \longrightarrow HCN + O$ (73)
$CH_2 + OH \longrightarrow CH_2O + H$ (35)	$C + NO \longrightarrow CN + O$ (74)
$CH_2 + OH = CH + H_2O$ (36)	$C + NO \longrightarrow N + CO$ (75)
$CH_2 + O_2 \longrightarrow CH_2O + O$ (37)	$N + CO_2 = NO + CO$ (76)
$CH_2 + O_2 \longrightarrow CO_2 + H_2$ (38)	$N + CH_2 \longrightarrow HCN + 2H$ (77)
$CH_2(S) + M = CH_2 + M$ (39)	

Zone models [21,22] can be applied to understand the fire environment with a certain design fire. This is based on a two-layer picture with heat and mass transferred through the fire-induced plume. There are eleven key equations derived from physical laws and seven constraints, giving four ordinary differential equations to solve. However, care should be taken for tall buildings and buildings with large floor areas. Concerns that can be jotted down immediately are:

- Time taken for a smoke layer to develop in large buildings.
- Traveling time of smoke front up a tall building.
- Assessment of the ventilation opening conditions.

Fire field models or application of Computational Fluid Dynamics (CFD) or Numerical Heat Transfer (NHT) [e.g. 22,24,26] at the moment, is a natural convective problem. Air flow will be induced by the fire, taken as a thermal object. Conservation equations for the air flow variables are solved. Basically, there are three key elements [26]:

- Turbulence modeling.
- Algorithms for solving the velocity-pressure linked equations.
- Discretization scheme on the convective term appeared in the conservation equations.

Since combustion chemistry, thermal radiation and turbulence have to be simulated together, heat release rate should be put in the CFD/NHT packages [26]. Therefore, this approach is good only for studying smoke movement at the moment. It appears to have some CFD/NHT packages capable of simulating a fire [e.g. 33,34]. However, empirical parameters still have to be used. Simulation from the first principles with intermediate chemistry is not yet possible as explained in above [35]. Problems encountered in addition to the hardware constraints are:

- Assignment of free boundaries by extending the computing domains to outside the building.
- Although some CFD/NHT packages are user-friendly, theories behind should be well understood. Experts are required to carry out simulations for studying fire-induced air flow, not just relying on an engineer without good training.

Note that CFD/NHT itself is a rapidly developing subject. Even in describing the turbulent effects, there had been lots of arguments on using different approaches such as Reynolds Averaging the Navier-Stokes (RANS) equation [36] or Large-eddy simulations (LES) with subgrid-scale model [e.g. 33,34].

Fire models, both zone and field, were applied where necessary. There had been arguments on different issues while applying fire models in Hong Kong:

- Design fire

  As described above, this is the input parameter for almost all fire models. There had been lots of arguments on taking the heat release rate of a design fire as, say 0.5 MW in a big railway terminal.

- Use of zone model

  There was another project on simulating smoke movement in a long and narrow corridor. A two-layer zone model was used without dividing the compartment into multi-zones. Again, that was picked out with the design to be revised.

- Turbulence model

  CFD/NHT had been used once for studying the fire-induced flow without a turbulence model! That was considered not acceptable without physical justification.

- Evacuation model

  In studying the evacuation patterns, evacuation models were used frequently. The psychological effects of local citizens were also queried. Sometimes, field measurements on the evacuation pattern and total evacuation time were required.

From past experience on FSE, the following are recommended:

- Zone model

  This is recommended to understand the fire environment with a certain design fire. However, care should be taken on the geometry of the building. Height and floor area should be watched. The time taken for a smoke layer to develop is to be included in a building with a large height to cross-sectional area aspect ratio. Ventilation opening arrangement should be assessed as airflow though horizontal ceiling vent is difficult to estimate. Whether hot smoke can move out or cool air will be pushed in depends on buoyancy.

- Fire field (CFD/NHT) model

  This is good only for studying smoke movement at the moment. Care should be taken while specifying the boundary conditions. Free boundaries should be assigned where appropriate by extending the computing domains to outside the building. In this way, the neutral plane height can be predicted.

Anyway, there are still opportunities in developing fire models for EPBFC. One of the objectives in this 973 project is to develop a new generation of fire model!

6. FIRE ENGINEERING APPROACH IN HONG KONG

In Hong Kong, FEA will be considered [18] for those buildings where prescriptive fire codes on passive building construction cannot be followed as in Fig. 2. There is no EPBFC at the moment but a Fire Safety Committee (FSC) has been set up by BD in 1998 to consider all fire safety designs with FEA. This committee is chaired by an Assistant Director responsible for regulations control and a Chief Building Surveyor (Fire), other Chief Building Surveyors, Chief Structural Engineers, a representative expert from FSD, and two local members who are not officers of the local government but with some knowledge of fire engineering. Experts would be called upon when required. Minutes of the meetings were put onto the website of BD and so the design criteria, methods of approval and the fire safety objective to be achieved are open to be assessed. In fact, the approved drawings kept by BD can always be inspected by any person to see whether there are illegal structures before purchasing a property.

There are not yet standard methods for assessing those designs. Approaches used in overseas such as technical report BS ISO/TR 13387-1:1999 [10,13] in UK, American approaches [12,14] and Japanese approaches [11] were considered. FEA at the moment is not yet a detailed code as others. For example, there are three parts on documentation, design levels and topic specific intent in the drafted code [19] of International Code Council (ICC). The following items are judged, if necessary:

- Fire safety objectives and acceptance criteria.
- Design parameters.
- Characterization of buildings and its occupants.
- Identification of potential fire hazard scenarios and their possible consequences.
- Assessment against the safety criteria.

But in most cases, the parts deviated from the prescriptive codes for passive building construction would be assessed. An example is the non-compliance of FRC code [4] for glazing. Therefore, application of the FEA for most projects is to demonstrate the equivalency to prescriptive codes.

For studying fire safety problems, three parts, two on 'hardware' and one on 'software' will be considered:

- Hardware provision
  - Architectural features including passive building design construction.
  - Active fire protection systems basically following FSI code.
- Software provision

  Fire safety management with a fire safety plan including maintenance plan; staff training plan; fire action plan; and fire prevention plan for bigger organizations.

Knowledge of fire science and engineering was applied together with practical experience under local conditions. Mathematical fire models [21-26], either zone models or field models (application of CFD/NHT), had been used to analyze potential fire scenarios. However, full-scale burning tests, scale models studies and site measurements on evacuation pattern might be required to demonstrate the design.

There are three levels of study for FEA design:

- Basic study
- Intermediate study
- Advanced study

'Basic study' projects are those which can get the results easily. Only those accepted empirical equations in Fire Dynamics are used. Most likely, there are track record to similar design. An example is to study wall at the sides of a link bridge higher than the specified value of 1.2 m.

'Intermediate study' projects are those which can be analyzed by using established fire engineering tools. Similar projects, though not exactly the same, had been carried out before so that past experience can be shared. An example is to assess the safety aspects for a car park having 'travel distance' slightly longer than the values specified in the prescriptive fire codes.

'Advanced study' projects are those involving full-scale burning tests and fire models in assessing the consequences of different fire scenarios. The problem itself might not necessarily be complicated, but there were no previous studies nor past track record of design. Therefore, it is difficult to identify the problems for reference. An example is whether vertical spandrel can be substituted by horizontal apron. Both CFD studies and full-scale burning tests are required.

Anyway, all three levels of projects should be analyzed carefully as safety provision is an important issue. A detailed report will be submitted to clarify how the safety problems encountered will be solved. Assessment by FSC is very vigorous and so the study must be carried out seriously.

7. IMPACTS OF FIRE SAFETY ENGINEERING

Prescriptive fire codes have been developed for many years. The codes are clearly presented so that both building designers and officers are familiar with. However, the codes might not be updated rapidly for buildings with new architectural features. New building types, new materials, new systems and new style of living would make the situation even more complicated. Enforcing prescriptive codes may end up either killing innovative building design or failing to maintain adequate fire safety.

But there are difficulties in implementing EPBFC as experienced in overseas. Many questions were raised on the acceptable level of fire safety; factors limiting the possible solutions; fire hazards and their consequences; fire safety provisions; design scenarios and method of analysis. In fact, an essential question to ask is how performance requirements should be specified. Those requirements include human safety, prevention of spread hazards, assurance of fire-fighters access, and many others.

An alternative solution is to upgrade the prescriptive codes at regular intervals, say once every three years. During the transition period, FEA is applied.

Anyway, engineering tools are required in applying fire safety engineering. There is still room for improving the accuracy of those fire engineering tools such as fire models. Validation of those models is particularly important. As pointed out recently [37], both building designers and relevant government officials should be properly trained in using fire models. Note that the development of fire model itself is very rapid. For example, three-dimensional simulation with CFD models can be handled readily with a personal computer now. But 15 years ago, only two-dimensional simulation could be carried out in a mainframe computer.

Education and training [38] is the key issue. Continued professional development on introducing the advanced topics in fire safety engineering must be offered regularly. Long-term planning to train fire engineers starting from new degree programmes is necessary. Obviously, research projects at PhD degree level cannot be missed.

8. CONCLUSIONS

Three aspects on passive building construction, active fire protection system and fire safety management must be considered for total fire safety. With the rapid development of new materials and products, and new architectural features, EPBFC [8-14] should be considered. Adequate, not more nor less, fire safety can be achieved for buildings, especially those of unusual geometrical design with new architectural features.

Fire models [21-26] had been used in many projects but leading to many arguments and debates on some submodels of those available tools. If the results are not demonstrated clearly, say by full-scale burning test, the process would appear as a 'curve-fitting exercise'. At least, verification exercises must be performed. Although the associated costs for doing the tests might be high, it is necessary to demonstrate the fire safety aspects.

Before taking actions on revising the codes or trying to implement EPBFC, an immediate action is to enhance fire safety management. The fire safety provisions, both hardware and software, were surveyed recently, to obtain a better and updated background picture. A ranking system was proposed to assess the fire safety provisions in all types of buildings and to compare with the new codes. The results would then be useful for upgrading the fire safety provisions in existing buildings deviated from the new expectations. Fire safety management program [17] can then be worked out.

Further, education and training [38] must be provided. Offering degree programmes up to MSc level is necessary for upgrading the quality of fire engineering personnel.

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