ELSEVIER

Available online at www.sciencedirect.com
ScienceDirect

Procedia Engineering 11 (2011) 583–592

Engineering Procedia

The 5th Conference on Performance-based Fire and Fire Protection Engineering

Challenges of Fire Fighting in Fire Engineered Built Environment

Y C Wang[a,*], J Marsden[b], M Kelly[c]

[a]University of Manchester, UK
[b]Formerly Greater Manchester Fire and Rescue Service, UK
[c]Greater Manchester Fire and Rescue Service, UK

Abstract

Performance based fire engineering design, as opposed to the traditional approach of satisfying highly prescriptive rules, is increasingly being taken up by clients and their professional advisers, including architects and engineers, because the performance based design approach can be used to offer a more attractive design through cost saving and greater design flexibility. However, fire engineering solutions make different assumptions on fire services intervention and are based on a number of engineering and management assumptions. These assumptions have implications on activities of the fire authority, in particular, fire fighting activities and these should, at the design stage, be addressed by the fire engineering design team. It is also important that the fire authority works closely with the fire engineering design team so that the fire engineering assumptions are not invalidated by fire service intervention. This paper identifies a number of challenges facing both the fire engineering design team and the fire authority and discusses how some of the challenges may be tackled.

Keywords: fire engineering; fire fighting; roles of fire authority; fire strategy

1. Introduction

Achieving fire safety in the built environment requires contributions from a number of organisations. During the design stage, professional designers such as architects and engineers, in consultation with the fire authority (FA), develop a fire strategy to satisfy the regulatory and business requirements of fire safety. During the operation stage, the building should be maintained and operated by the owner in accordance with the fire safety strategy, audited by the FA. Should fire break out in a building, the fire and rescue service (FRS) of the FA is called upon to fight the fire.

For a building that is designed according to "deemed to satisfy" prescriptive rules, the above procedure is easily followed. Although there are some interactions between the FA and the fire safety design team at the design stage and between the FA and the building owner during the operation stage, the action of one organisation is essentially separated from those of the others. For example, Figure 1 illustrates the relationship (or lack of) between the

* Corresponding author.
E-mail address: yong.wang@manchester.ac.uk

doi:10.1016/j.proeng.2011.04.699

different parts of the prescriptive approach, based on the Approved Documents part B (ADB 2000) to the Building Regulations of England and Wales. Within this document consideration is given to fire fighter access (B5) in which facilities such as fire fighting lifts, access to the perimeter to the building, the provision of wet or dry risers and the provision of fire fighting water in or close to the building. These features have been based on a prescriptive design and it has been simply assumed that the prescriptive approach to fire fighter safety will suffice in the case of engineered buildings. It can of course be argued that the facilities afforded to fire fighters in both prescriptive and engineered designs are deemed to satisfy, but given the increase of height of buildings, the use of modern building materials and greater travel distances, greater emphasis should be given to fire fighter access within performance designs.

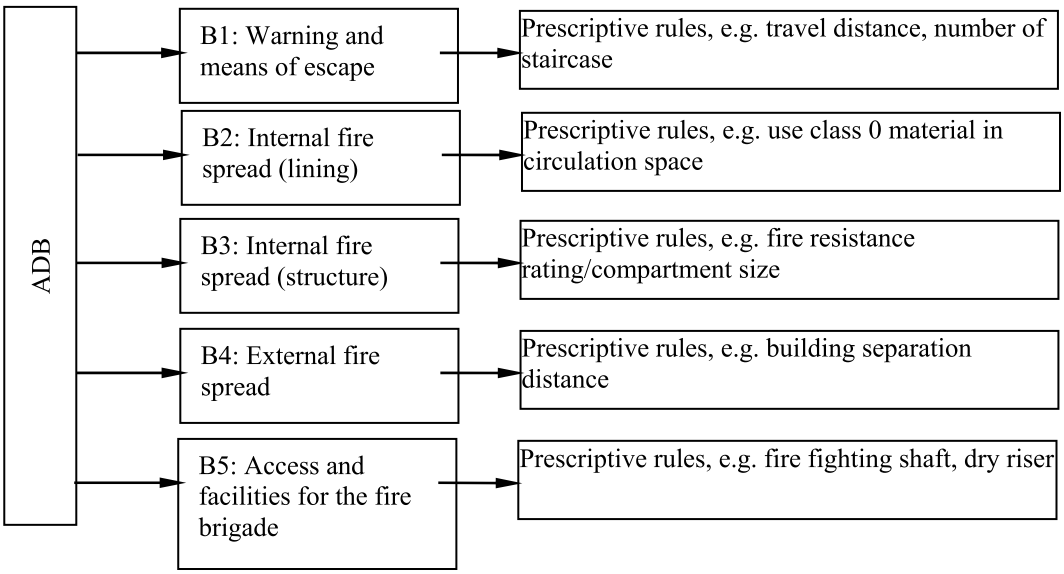

Figure 1: Components of prescriptive rules and lack of links between them

The traditional approach of following the prescriptive rules has proved to be able to limit fire risk to an acceptably low level, as evidenced by the relatively small amount of fire caused fatality and loss, compared to other causes such as road accidents. However, within the context of performance based fire engineering approach, the current practice will most certainly not be effective. Since the FA is the constant presence that links the different stages of fire safety activity of a building, interactions between the FA and other organisations, and between fire fighting activities and other actions, should be critically examined. This is the objective of this paper which aims to initiate a discussion on how to most effectively utilise the FA. Performance based (fire engineered) design solutions are considered to offer more flexible and cost-effective fire safety designs than the prescriptive approach. The use of performance based approach is inevitable which makes this discussion imperative.

2. FA’s Interactions with Fire Engineering Design and Their Roles

The FA’s roles are three-fold, as follows

(i) Statutory consultation: to ensure that the regulatory requirements (Building Regulations 2000) are complied with. This can be achieved by use of an Approved Document (ADB) or by the use of a performance design. Fire fighter access in the case of prescriptive design is clearly detailed within the design code but it is not clear or considered in the case of a performance based design. Within these cases it should be the FA, who assess the level of safety for fire fighting, who make their recommendations to the controlling body.

(ii) Legal enforcement: to ensure that the building owner maintain and operate the building according to the fire design strategy;

(iii) Fire fighting and rescue in the event of fire.

Within the prescriptive framework, the roles of the FA are clear. Since there is no alternative solution to the first two activities, the activity of fire fighting has no influence on the first two activities. The corollary is that fire fighting is independent of the other two activities so that there is no need to make any special provisions for fighting fire in any specific building (other than that given in the prescriptive approach). Because there is no link between fire safety provisions (other than fire fighting) and actual performance of the building and building occupants in fire, there is low confidence in the ability of fire safety provisions to minimise the effects of fire. Thus, fire fighting is considered essential to remedy any shortcomings that may exist in the fire safety provisions.

In performance based fire engineering solutions, the FA' roles should be critically examined. In fact, the need for the FA to exist can be questioned. From the point of view of enforcing fire regulations (to be referred to as legal roles), such a question would be considered preposterous. This will be discussed below. But the question arises when considering the more important issue of whether the FA activities, particularly fire fighting, provide enhancements to fire safety (to be referred to as rational roles).

2.1 Legal roles of the FA in fire engineering solutions

In England and Wales, the FA is a statutory consultation body. This means that the FA has to be consulted over the fire design strategy on fire fighting access and facilities. The FA may also raise issues that it considers appropriate. The FA is not the approval body and does not have the power to approve or reject the fire design strategy. This power rests with the Building Control Office (BCO). However, should the FA raise any issue over the fire safety strategy, there is no alternative but for the BCO to ensure that these issues are satisfactorily addressed by the fire design team. Otherwise, the BCO would be liable to future responsibilities should the issues identified by the FA, but not addressed by the fire design team, result in adverse consequences later. The BCO will not want to risk this. Knowing this arrangement, the fire safety design team has no alternative but to address the issues raised by the FA because otherwise the fire safety strategy would not be approved by the BCO.

The FA can only raise issues that it has the competency to do so. Therefore, although such an arrangement would always benefit the fire safety provisions, the extent of this benefit will depend on the expertise available within the particular FA. Not every FA has the ability to ask the appropriate questions.

As far as fire fighting is concerned, the British Standard for fire engineering, PD 7974 "Application of fire safety engineering principles to the design of buildings", Part 5 "Fire service intervention" states:

In the design of a building, it should be assumed that fire service operations do not contribute to the safe evacuation of occupants. Rescue by the fire service can provide an additional factor of safety, but this should not be taken into account in any design calculation of probable risk to the building or occupants.

However, the first concern of the fire service is to ensure that all persons are evacuated safely (or, in a building subject to phased evacuation, can safely remain in the building). Therefore, the fire service attack on the fire should normally be assumed to begin only after all the occupants are in a place of safety.

An analysis of fire service response is, therefore, likely to be of most benefit when considering what additional fire protection measures may be appropriate for the protection of property.

Put simply, if a fire engineered building performs as designed, there is no requirement for fire fighting as far as public safety is concerned. Since ensuring public safety is the primary reason for the existence of FA, the above statements imply that the FA's existence is of marginal benefit to a fire engineered building. Clearly, the public will demand the FA to fight fires regardless whether a building is designed following the prescriptive approach or the fire engineered approach. But to base one's existence on the public's lack of knowledge in fire engineering cannot be considered a sufficiently robust reason. This analysis is predicated on the fire engineering solution being truly based on the assumption that safe evacuation of occupants without fire service operations is explicitly checked.

Therefore, the legal roles of the FA are not in any dispute, but they have little rational value.

2.2 Rational roles of the FA

This paper is not in any way to advocate relieving some of duties of the FA. Far from it, this paper intends to identify more robust and positive reasons to justify the FA activities. It is only through clear understanding of the roles of the FA that more effective means of fulfilling these roles can be devised to enhance the services of the FA.

<u>Statutory consultation</u>

As mentioned in the last section, the FA is a statutory body that can raise issues with the fire design strategy. In order for the FA to make the most use of this position to enhance the fire design strategy, it is important that the FA has good knowledge of different aspects of fire engineering solutions so as to enable them to thoroughly examine the fire design strategy, to question the design based upon the resources, equipment, demographics and any other limitations the fire authority may have that may have an influence on the design due to height, size, location and complexity of the building. In particular, the FA should possess sound understanding of the scientific and engineering principles of fire engineering solutions to question the design concepts and assumptions and to judge the correctness of the design solutions. Only with such deep knowledge will the FA be able to decide whether their concerns on the fire design strategy have been adequately resolved. To meet this new demand on the FA, the Greater Manchester Fire Rescue and Services (GMFRS) has developed a Fire Engineering unit with fully trained operational fire engineers who deal exclusively with complex performance solutions. They work closely with the Fire Engineering Design team to develop fire safety design strategy.

For example, the GMFRS, as the responsible local FA, has been able to provide indispensible service to the Fire Engineering Design team to assist the team to develop the fire strategy for the Media City (figure 2). The Media City project is a £500 million building project that is currently under construction in Salford Quays, Greater Manchester, as part of the BBC's relocating some of its activities outside London. Among many issues raised, one was about fire fighting access and adequate supplies of water to the whole site. The following recommendations were made to ensure that the design strategy incorporated a degree of robustness and resilience into the design.

(i) Open water pump sites on at the water's edge
(ii) A ring main with Hydrants surrounding the site
(iii) All buildings to be sprinklered

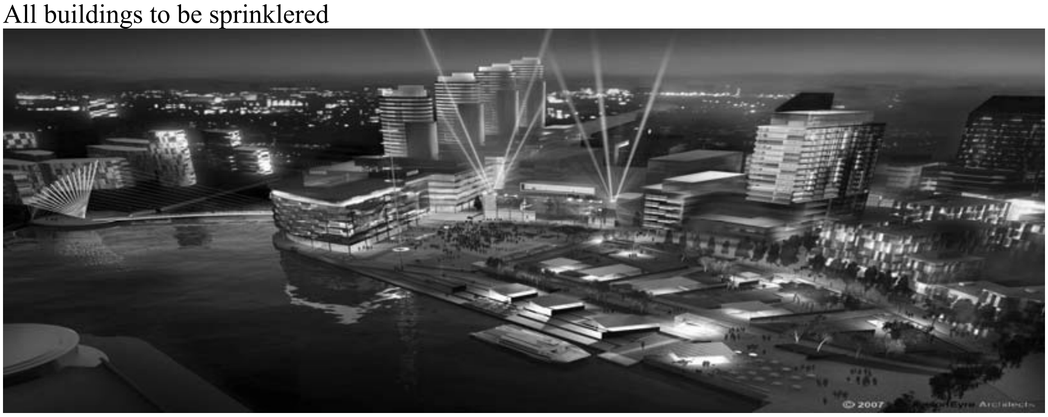

Figure 2: Media City, Salford Quays, UK

GMFRS also advised the Design Team to take into consideration the physiological effects upon the fire fighters when attending fires within the building including the fire fighting actions when using powered smoke extraction systems within escape corridors.

Legal Enforcement

A fire engineered solution has two outputs:

(i) the fire strategy, explaining the functional requirements of fire safety and quantitative demonstration using fundamental engineering principles how these requirements are satisfied;

(ii) the management/operation manual detailing how the building owner should manage and operate the building so that the assumptions adopted in the fire design strategy are not compromised.

Once a building is occupied and in use, the FA takes on the co-ordinating role as they have the enforcement role conferred by The Regulatory Reform (Fire Safety) Order. Again the FA should have thorough knowledge and understanding of the engineering concepts and assumptions of the fire strategy so that they can guide the building Owners in their management and operation of the building under normal use. For example, if the fire engineered solution to a shop specifies descending smoke curtains for smoke control, it is important for the FA to convey the fire engineered design intention to the Owners so that they do not obscure the space below the smoke curtains and also maintain fire engineering systems.

Fire Fighting

Among the three main roles of the FA, fire fighting will be the most affected. As previously explained (section 2.1), in a fire engineered building, safe occupant evacuation is not reliant on fire fighting and rescue. With this assumption, the main reason for employing fire fighting in a fire engineered building is to control the fire and minimise fire damage to the construction. This is a radical departure from the traditional emphasis of fire fighting where rescue of strangled occupants is the most important objective of fire fighting. There is an argument that if the purpose of fire fighting is not occupant rescue but property protection, then the cost of fire fighting should be borne by the building Owners and their insurance companies through the employment of private fire fighters. But it may also be argued that the notion of a publicly funded fire service in emergency fire fighting is deeply ingrained within the psyche of the public and it would be emotionally indefensible not to deploy the fire fighting service even though the purpose of fire fighting is to primarily benefit the building owners. Furthermore, sometimes the beneficiary will be more than just the building owners and their insurance company. Large amounts of resources are consumed to construct a building and its facilities. Saving as much as possible is in the best interest of the society in general. In some cases where employment is concerned, the local society associated with the building in fire would also benefit greatly if fire fighting helps to prevent the building activities from closing down and losing business.

Accepting that there will always be the need for fire fighting in fire engineered buildings, it is important that the fire fighting activities should consider the specific nature of the building. For example, GMFRS has the Operations/Fire Safety interface in which the fire engineering section enters into dialogue with the operations section to develop effective fire fighting plans. For the aforementioned Media City, due to the nature of the buildings, access is difficult for standard fire appliances and consideration has been given procuring smaller vehicles bespoke to Media City.

It is also important to recognise that changes have to be made to accommodate departures of fire safety provisions in fire engineered solutions from prescriptive solutions. First, as the emphasis of fire fighting changes from occupant rescue to property protection, this should be reflected in the practice of fire fighting in fire engineered buildings. Second, as the fire scenario in a fire engineered solution has not explicitly considered fire fighting, the consequence of fire fighting should be carefully considered so that it does not bring about adverse effects. These will be further expanded in the following section.

3. Implications and challenges of fire fighting in fire engineered built environment

As explained above, in a fire engineered solution, the emphasis of fire fighting (property and business protection) is different from the traditional role of fire fighting and rescue. Also many assumptions will have been made in a fire engineered solution. These will have wide implications and may necessitate some changes in the practice of fire fighting and fire engineering solutions.

3.1. Rescue activities and fire service resource allocation in fire fighting

Since it is assumed that occupant evacuation in a fire engineered solution does not depend on fire service intervention, then there is no need for the rescue activity. It is of course never possible to discount the possibility that rescue is necessary even for a fire engineered building, but it must be reasonable to accept that the risk of someone getting trapped within a fire engineered building is very low. In any case, fire service resource allocation should be carefully considered so that the fire fighting team does not automatically engage in futile and unnecessary rescue activities. Since the main objective of fire fighting in a fire engineered building is to protect property, then it is probably best leaving the fire to burn out when the probability of saving the building through fire fighting is very slim. For example, figure 3 shows a timber structure in fire. The chance of saving the building is probably not even worth considering.

Figure 3: A timber structure in fire

It is unfortunate, but practical, that at present, the scope of fire engineered solutions can range widely, from employing an alternative solution to tweak a small part of an otherwise prescriptive design, to a solution that starts from first principles of fire behaviour and occupants response. The argument in the previous paragraph is predicated on the evacuation design to be fire engineered, to demonstrate that occupants can evacuate safely under different credible fire scenarios (Available Safe Escape Time > Required Safety Escape Time). Should means of escape design be still based on prescriptive rules, e.g. limiting travel distance but other aspects are fire engineered (e.g. structural fire protection), then the traditional function of fire service intervention (fire fighting and rescue) will still apply.

3.2. Adverse effects of fire fighting

Whilst the intention of fire fighting, which is to minimise fire damage, is never in doubt, fire fighting may in some cases not bring about the desired effects and the consequence of fire fighting may even be worse than leaving the fire to naturally die out.

For example, figure 4 illustrates the intended smoke movement in a fire engineered solution. Sufficient smoke venting results in a stabilising smoke layer above the occupants to enable them to evacuate. Fire fighting using water may increase the smoke density and drag down the smoke layer, impeding evacuation.

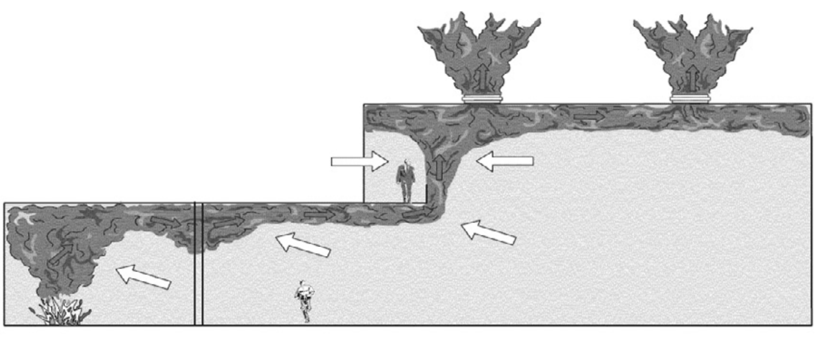

Figure 4: A fire engineered smoke control system

In structural fire engineering, the use of innovative materials can be justified based on their performance under the design fire scenario. In most cases, this does not cause any problem. But water damage from fire fighting may worsen the material performance. For example, if a steel structure is protected by intumescent coating, then water jet from fire fighting may destroy the intumescent char, resulting in the loss of effectiveness of the fire protection material. Concrete spalling is primarily a result of high moisture inside the concrete. Water from fire fighting may increase the water content in concrete and cause more extensive spalling. Traditionally, assessment of structural behaviour is based on single elements without any restraint in the longitudinal direction of the member. Reduction in temperature is always considered to be beneficial. But structural members in real structures are subject to restraints and cooling may introduce tensile stress and result in structural fracture. For example, figure 5 shows a fractured connection during cooling (not as a result of fire fighting). Accelerated cooling due to fire fighting may result in more extensive fracture. Ideally, under these circumstances, the fire fighters should direct their water jet away from the loadbearing structural components. But this is on the assumption that the fire fighters can differentiate the loadbearing and non-load bearing members of a construction.

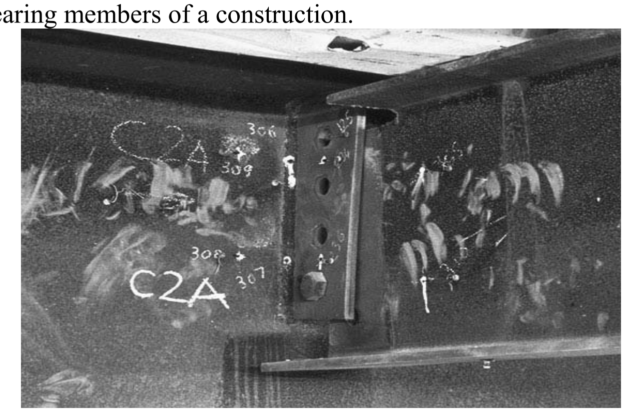

Figure 5: Fracture of connection during cooling, Cardington fire test (Newman et al 2006)

3.3. Structural fire resistance of non-evacuation route

When the emphasis of fire service intervention is on occupant rescue, rather than property protection, the structure that does not form part of the escape route does not require fire resistance. However, this should be reconsidered in some cases if saving the structure becomes the overriding objective of fire service intervention.

For example, in the UK, steel portal frames are ubiquitous and account for over 90% of single storey industrial structures. Because of the low number of occupants in portal frame structures, there is no requirement of fire resistance for portal frame structures (within the UK a roof is not classed as an element of structure). Each portal of a portal frame is essentially one structural element. If its fire resistance is low because there is no requirement for it to have fire resistance, then its collapse is total (Figure 6) and can happen within a short time, leaving the fire fighters with little time to escape. Therefore, if fire fighting is essential in a new portal frame, safety of the fire fighters should be considered. This may mean that even portal frames not within boundary condition should be designed to remain standing in fire so as to enable the fire fighters to fight and put out the fire.

Figure 6: A collapsed portal frame structure

3.4. Contribution of fire fighting to fire engineering solutions

As mentioned in section 2.1, the fire engineering assumption is that fire fighting should not be relied upon to help occupant evacuation. Although this is understandable because it can be difficult to accurately and reliably predict the fire brigade arriving time, there is no reason why it would not be possible to improve the predictability and reliability of fire brigade arrival time. Should this happen, it would be possible to incorporate fire fighting within a fire engineered solution. This is different from the provision of fire fighting access and facilities to the fire brigade. It is about positively taking advantage of the fire brigade putting out or controlling the fire on the time line of the fire. In fact, under the Natural Fire Safety Concept in Eurocode 1, it is possible to take advantage of fire brigade proximity to reduce the required fire resistance rating of a structure.

3.5. Effectiveness of fire fighting

Performance based design should not be just restricted to the safety of occupants of the building escaping in the case of fire, but the design team should consider safety applications in their entirety and include the safety of fire fighters and other rescue services entering the building after the occupants have escaped. It is highly likely that conditions will be untenable in the area surrounding the fire such that additional protection will be required such as breathing apparatus and protective clothing.

It is therefore important that in the planning or concept stage that the design team consider all aspects of the performance solution and in order to achieve this all stakeholders, including the fire and rescue service, should be present. The fire strategy developed should not just confine its content for the means of escape phases when it is most likely that the fire will in its early stages. This strategy should include an analysis of the conditions at the time that fire fighters will be entering the building to extinguish the fire, such parameters such as temperature, fire size and visibility should be considered.

Marsden (2009) identified a number of issues that should be tackled by the fire engineering design team to enable the fire fighters to effective fight fire. Such issues include:

(i) Buildings with tightly sealed, highly insulating façade (e.g. Figure 7). In such a building, it will be difficult for the fire to vent. If the façade is opened by fire fighters, there would be greater chance of back draft and flashover and greater fire spread within the building.

Figure 7: Behaviour of fire in buildings with sealed façade

(ii) Fire engineering features. The actions and safety of attending fire fighters can be greatly affected by the fire engineered features that are installed within a particular building design. For example smoke control systems have the ability to maintain conditions such they are tenable in the means of escape phase for the occupants, but in the case of the fire and rescue service the conditions may have deteriorated such that the smoke control system is overwhelmed by the fire growth thus resulting in the possible smoke logging of the fire floor which will result in reduced visibility, tenability and increased temperatures.

(iii) Construction stage fire (e.g. Figure 8). The design of complex and tall buildings is such that in the construction phase, important features such as compartmentation, protected escape stairs, fire protection to structure, fire fighting features and smoke control systems may not be installed. The lack of these features is such that if a fire starts its spread throughout the building may be unrestricted resulting in premature collapse and limited fire fighter actions on arrival. It is important within fire engineered strategies that the construction phase is adequately risk assessed as it may be a only at the later stages of construction that fire fighting features such as those described above are installed.

Figure 8: Lack of firefighting provisions in buildings under construction

(iv) Physical limits of fire fighting. Physiological effects upon fire fighters need to be considered because the effects of heat and fire fighting operations can have a marked effect upon the physical performance of fire fighters such that the fire conditions are such that fire fighters will succumb to these effects and may not be able to effectively reach the fire. This consideration may invalidate some of the fire engineering solutions. For example, in the case of residential developments, single staircase designs are being proposed with corridor lengths exceeding 15m and mechanical smoke systems, instead of the prescriptive approach of 7.5m with natural ventilation. The result of this is that firefighters have to traverse longer distances to carry out operations.

This increased distance may only equate to a few more seconds in the occupants' evacuation time, but the fire fighters may have to take much longer time to travel due to the difficult conditions within the building.

4. Conclusions

This paper has identified a few challenges of fire fighting in fire engineered built environment. These are:

i) Development of fire engineering expertise with fire authorities (FA) to enable the FA to provide better advice to the design team and to develop thorough understanding of the design concepts and engineering assumptions;
ii) Close working between the fire engineering design team and FA. With FA, there is a wide range of expertise of fighting fires within buildings. It is important to understand that this experience may not have been encountered by the design engineers who may have not had exposure to fire development within buildings.
iii) Assessment of the role of fire service intervention. Within the framework of prescriptive design, fire safety provisions are designed on the assumption that the fire service will need to search and rescue trapped occupants. Fire engineered solutions assume that occupants do not rely on fire fighters for evacuation and the main purpose of fire fighting is for property and business protection.
iv) Possible adverse effects of fire fighting. It is important that fire fighting does not adversely compromise fire engineering design assumptions.
v) Fire resistance of non-evacuation routes. Even though structures within non-evacuation routes do not require fire resistance within the prescriptive approach, performance based approach may have to consider providing the structure with fire resistance to ensure effective fire fighting.
vi) Incorporation of fire fighting within fire engineering solution. Wherever fire fighting can be reliably provided and predicted, this should be incorporated into the fire design strategy when defining the fire scenario.
vii) Limits of fire fighting. The fire engineered solution should consider the physiological limits of fire fighters, the tenability condition of fire fighters and the unsuitability of traditional fire fighting techniques to deal with new construction methods.

These issues should be carefully addressed by the fire engineering design team and the fire authority. Where information is lacking, further research studies should be carried out.

Disclaimer

this paper has come about as a result of a number of discussions by the authors. The views expressed in this paper do not represent that of the Greater Manchester Fire Rescue and Services.

References

[1] Department of the Environment and The Welsh Office (2000), Approved Document B, Fire Safety (as amended 2000), The Stationery Office, London, UK

[2] British Standards Institution (BSI 2001), BS 7974: 2001: Application of fire safety engineering principles to the design of buildings. Code of practice, Part 5: Fire service intervention, British Standards Institution, London, UK

[3] Marsden, J. (2009), Building barriers, Firefighter Safety Management, June 2009, pp. 51-54

[4] Newman G.M., Robinson J.T. and Bailey C.G. (2006), Fire Safe Design; A New Approach to Multi-Storey Steel-Framed Buildings (second edition). SCI Publication P288. The Steel Construction Institute, Ascot, UK

[5] Simms, W.I. and Newman, G.M. (2002), Single Storey Steel Framed Buildings in Fire Boundary Conditions, Publication P313, Steel Construction Institute, Ascot, UK