BRUSSELS INTERNATIONAL AIRPORT

FIRE SAFETY ENGINEERING APPROACH FOR THE NEW "PIER A AND TOPAAS"

Jean-Claude S. **De Smedt**, MIFireE
Managing Director n.v. IFSET s.a. – Belgium
and FRS/IFSET Asia Ltd – Hong Kong

Howard P**. Morgan**, BSc PhD CPhys MinstP FIFireE
Principal Fire Consultant Fire & Risk Sciences Division (BRE)
and Technical Director FRS/IFSET Asia Ltd – Hong Kong

0. ABSTRACT

The Brussels International Airport Company (BIAC) has built an extension to the existing Airport. The development comprises building a new Pier (Pier A) and also modifying and developing the existing Topaas which forms a link via an existing tunnel between the current airport terminal and Pier A. 'PIER A' is 650 m long, 38 m wide and 14 m high with a number of levels including baggage handling at basement level and access to aircraft at the 'first floor' level; there are also a number of shops and hospitality suites at this level. The Topaas resembles a shopping mall with an atrium with more specialized ancillary rooms, and airline lounges in the highest storey. Escalators and lifts join these levels. It was not possible for the complex to comply with the King's Decree in all regards. However, it was possible to do an alternative design based on principles of Fire Safety Engineering (FSE), which achieved at least the same level of safety as with a design following the prescriptive Codes. This approach has used a combination of prescriptive Codes (where appropriate) and innovative alternative designs elsewhere. FSE has required use of mathematical modelling and novel techniques based on sound fire safety principles. Often, such designs are aesthetically more pleasing and less expensive.

BIAC commissioned IFSET and FRS as Fire Safety consultants to develop an alternative fire safety design based on FSE principles. The design included sprinklers, smoke and heat exhaust ventilation systems (SHEVS), separation using compartmentation and other necessary measures.
A derogation request has been submitted to the Ministry of Interior and accepted.
Zone modelling, CFD modelling and egress modelling have been used in this design. Also a full fire risk analysis with real fire tests under the sprinklered calorimeter has been done.

The paper will describe all the techniques used in this project and shows that FSE can successfully be applied into practice.

1. INTRODUCTION

1.1 Background and objective

In 1998, The Brussels International Airport Company (BIAC) decided to build an extension to the existing Airport.

In the meantime, the development is almost finished and comprised building a new Pier (Pier A) and also modifying and developing the existing Topaas which forms a link via an existing tunnel between the current airport terminal and Pier A. The 'PIER A' is about 650 m long and 28 m wide with a number of levels including baggage handling at basement level and access to aircraft at the 'first floor' level; there are also a number of shops and hospitality suites at this level. The Topaas resembles a shopping mall with an atrium with more specialised ancillary rooms, and airline lounges in the highest storey. There are escalators and lifts joining these levels.
It was not possible for the complex to comply with the King's Decree in all regards. However, it was possible to do an alternative design based on principles of Fire Safety Engineering (FSE), which achieved at least the same level of safety as with a design following the prescriptive Codes. This approach has used a combination of prescriptive Codes (where appropriate) and innovative alternative designs elsewhere. FSE often require use of mathematical modelling and novel techniques based on sound fire safety principles. Often, such designs are aesthetically more pleasing and less expensive.

There was an existing fire safety design for the proposed development, which relies primarily on compliance with the King's Decree although it seeks 'Derogation' on some aspects, e.g. escape times. BIAC commissioned IFSET and FRS as consultants to develop an alternative fire safety design that will be based on FSE principles. It was anticipated that the design would include sprinklers, smoke and heat exhaust ventilation systems (SHEVS), separation using compartmentation and other necessary measures. It is emphasised that the IFSET/FRS brief was to carry out a concept design only, with the detailed engineering design being done by others.

1.2 Scope of work

The proposed development is a large and complex structure and the different areas can be expected to have their different problems requiring different solutions. Some of the potential difficulties and the solution approaches are described below.

Pier A is a large undivided volume where in the event of an uncontrolled or a large fire smoke and hot gases have the potential to travel long distances and smokelog areas away from the fire creating potentially hazardous conditions. An airport Pier cannot easily be subdivided into smaller fire-resisting compartments. Even though it is possible to create different smoke zones using smoke curtains this would be difficult to implement due to the 'curved' ceiling – it will also be expensive. An alternative FSE-solution, which could keep the Pier as a single undivided volume, would be less expensive and also more aesthetically pleasing.

The aluminium roof and the steel structure of the Pier A need 1 hour fire resistance to comply with the King's decree. If a strategy is devised such that a low enough temperature can be maintained in the Pier in the event of a fire then the steel structure would not need additional fire resistance which would produce a significant cost saving.

In regulatory terms, Pier A is a 'low building' and the Topaas is a 'medium high' building and a 4 hours fire separation (2 hour for doors) between the two buildings is required. Considering the whole complex as a single building for FSE calculations will remove the need for the separation.

The Topaas comprises shops, restaurant(s) and executive lounges at various levels as well as a central atrium spanning all levels. Also there are escalators, which are open at each level. An acceptable FSE solution would be to prevent smoke in the atrium from adversely affecting escape routes on the storeys open to the atrium, and to prevent smoke from larger fires from entering the atrium at all. It will then not be necessary to separate the atrium from the adjoining space.

The consultancy proposal submitted to BIAC envisaged following procedures and methodologies to be used in the FSE design:

- Divide the complex into zones taking into account natural boundaries (e.g. walls), areas of open spaces, usage, contents and any other special requirements.
- Use a suitable design fire for each zone – choice of fire size.
- Smoke filling, temperature distribution and available escape times are calculated using zone and computational fluid dynamics models. It was envisaged that the FRS in-house CFD model, JASMINE, would be used where Zone modelling is inappropriate.
- A suitable state of the art egress model (CRISP) has been used to model evacuation.
- Guidance on suitable detection and alarm system, including voice alarm and intelligent signage, have been provided.
- Advice has been given on fire control methods, e.g. sprinklers.
- Fire resistance requirements of various components have been assessed – this will depend on the calculated temperature history of the particular area in the event of a fire.
- The study has considered other relevant measures such as fire shutters or smoke curtains, fire resisting furniture (where needed), smoke and heat exhaust ventilation systems (SHEVS), et cetera.
- Location of first-aid fire fighting equipment and dedicated Fire Services equipment have been considered.
- Fire safety management strategy including availability of trained staff have been briefly discussed.

2. Fire Safety Codes - Prescriptive or Performance

An alternative approach has been to allow any combination of fire precautions, which achieve a required minimum level of safety, subject to confirmation by the regulator that the methods used have been:

- appropriate to the problem;
- correctly applied;
- and meet the intentions of the Regulations.

This approach to achieving safety is described as being “Performance-Based”. This approach allows for innovation without any difficulty, but can be more controversial.

Since 1985 the U.K. Building Regulations have been completely performance-based, although the supporting documents provide a fully prescriptive approach for the most commonly found types of building.

At the same time as these developments, there was a growing feeling that a Standard Code of Practice was desirable to provide an agreed structure for the application of Fire Safety Engineering principles. This has lead to the drafting of a British Standard Draft for Development (BS DD 240), which is currently being reviewed in the light of comments received; and to work currently under way in ISO, the International Organisation for Standards, to produce an equivalent draft. Meanwhile there is a trend to rewrite Means of Escape and other Standards in a form which facilitates the use of FSE, by specifying the critical limiting values of important parameters without specifying a mandatory calculation methodology. Examples in the UK include BS 5588 Part 10, 1991, BS 5588 Part 7, 1997, and the current drafting of the new BS 9999 series.

CEN has not yet agreed to the preparation of a European Standard for Fire Safety Engineering, although this is said to be only a matter of time. It is probable that the ISO draft will provide a starting point. Meanwhile design ENs in the field of smoke control using “Normative” critical values for parameters, and “Informative” calculation procedures are still controversial.

The fire safety strategy proposals described in this Report follow the same principle of trying to achieve levels of safety at least as good as would have been obtained by following prescriptive rules, while departing from those prescribed rules in many ways. The prescriptive codes (in this case the King’s Decree) will be followed except where specific derogations will be sought for performance-based departures from the code. All such departures will be presented in this Report with a rationale justifying that departure.

In particular it should be noted that for the purposes of this Project the expression “the building” comprises both Pier A and the Topaas as currently proposed. Pier A and the Topaas form a single structure of different heights, and it is suggested that for the purposes of this fire safety strategy the entire structure is considered as a single integrated object. This recognises that the fire safety strategy outlined herein is NOT based on the King's Decree distinction between buildings of different heights. Instead the entire structure is treated as a single building, and recognises the need for any Derogations arising therefrom.

3 Fire Safety Engineering Strategy

3.1 Objectives

3.1.1 Primary:

To minimise any potential for the loss of life in the case of a fire incident, and to ensure that everyone in the building can escape unharmed.

3.1.2 Secondary:

a) To minimise the amount of fire damage
b) To minimise the cost of repair and reinstatement after a fire
c) To minimise consequential losses (e.g. loss of revenue due to the building being out of use after a fire) during the period of firefighting and repair
d) To reduce the total cost of fire protection measures in the building without compromising the foregoing objectives.
e) To allow a building design giving maximum flexibility of use under normal operations while remaining compatible with the foregoing objectives.

3.2 Fire Safety Engineering principles – BS DD 240, 1997

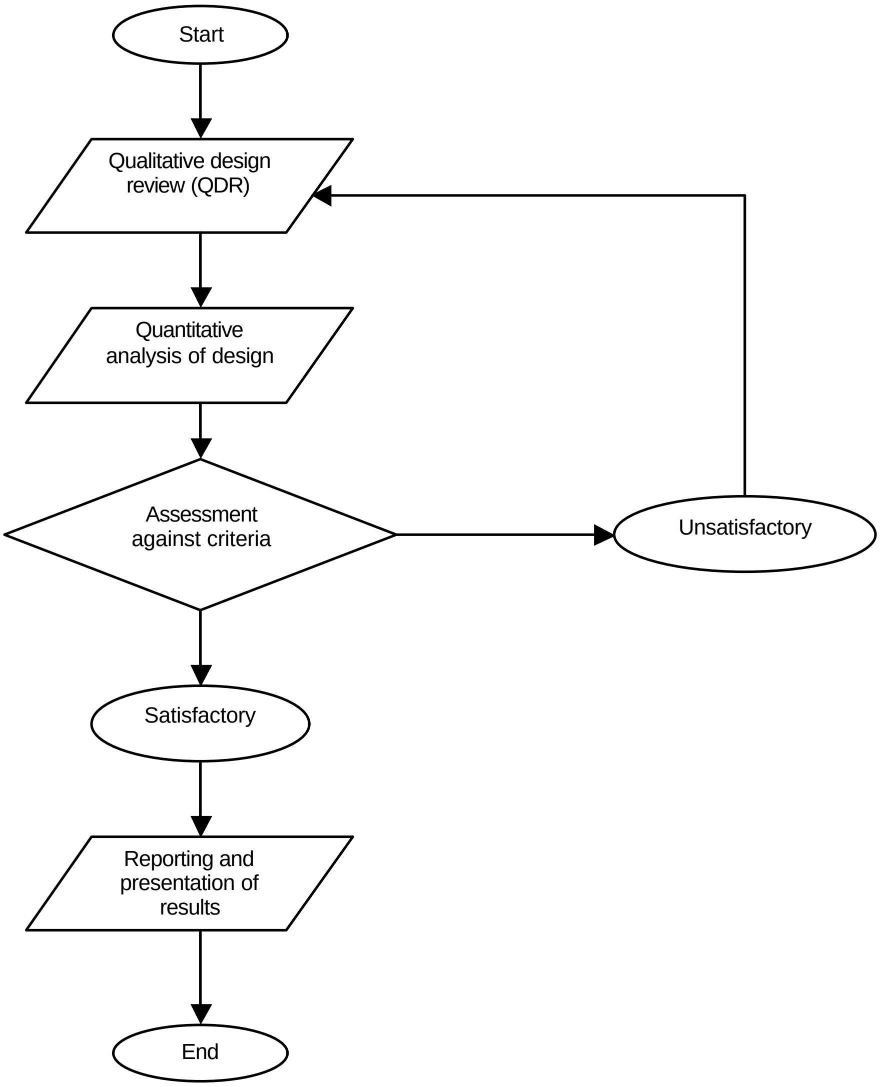
In the early 1990s moves began in the U.K. to prepare a Standard Code of Practice, which would guide both the designer and the regulator in how to apply FSE principles to a building. This idea was (and still is) full of traps for the unwary drafter of such Standards. For example, FSE is now an academic discipline, and academic disciplines cannot by their very nature be standardised. Nevertheless, it was felt that it would be useful to prepare a document that identifies which problems should be considered in fire safety design, and in which order they should be tackled.

This lead to the preparation of what became British Standard Draft for Development DD 240, 1997, and to the simultaneous development of the initially similar, but now diverging, ISO draft on FSE (not yet published). DD240 attempts to lead the user through all the aspects that might influence the designer of fire safety for buildings, including the psychological and physical aspects of human behaviour. Risk analysis is introduced as an important technique for assessing the overall threat, and to establish the relative importance of different fire precautions for the circumstances of the individual building. It very clearly recommends the creation of a design review team to treat the entire building in an integrated manner. It establishes a "route map" which can be followed from problem to problem, and points the way to solution methods for each problem, in a systematic way. Inevitably in any such systematic approach, large areas have been revealed as needing further research to supply the data needed by the designers.

DD 240 is still very controversial. Some argue that the inclusion of design equations has lead to the inclusion of too few/too many/too complicated/too simple formulae. There is a strong view that the detailed design formulae in DD 240 should be ignored and that more detailed external sources of design information should be used instead. The DD would then serve to guide the user on how to integrate those generic procedures without having to focus on a single procedure, which might be soon replaced by new research leading to better methods. This is the approach, which has been followed by the designers, who have preferred to use the latest methods based on well-founded research, rather than the excessively simple formulae in many parts of the DD.

Perhaps the most important thing to realise about DD 240 is that it is not a full British Standard. Its publication as a Draft for Development was, in effect, an opportunity for the design and regulatory community to gain experience in its use and to submit comments back into BSI for its amendment. This process of amendment has started, and BSI has recently (at the time of writing the BIAC report) asked for Consultants to tender for the production of redrafts of the constituent sections of DD 240 with a view to its conversion into a full standard. It follows that it is too early to know what the final standard will look like. It is possible – some would say likely – that the final standard will look very different to the published Draft for Development.

The basic fire safety design procedure is outlined in Figure 1 of the DD



The first most important stage is to produce an outline strategy based on recognition of the real objectives of the design, and to identify the key performance criteria as well as to identify what additional data is required. It is also at this stage that different alternative solutions can be considered. This process is termed in the DD the Qualitative Design Review. This is to be kept as a written document, although it must be recognised that the details, and sometimes major aspects of the proposals, may have to change as the subsequent quantitative analysis demands. The design team met several times during this phase, together with preliminary meetings with BIAC and the regulatory authorities, to confirm that all concerns and interests had been properly taken into account.

The Quantitative stage of the analysis is expressed in DD 240 in terms of sub-systems. These are:
Sub-system 1: initiation and development of fire within the enclosure of origin
Sub-system 2: spread of smoke and toxic gases within and beyond the enclosure of origin
Sub-system 3: fire spread beyond the enclosure of origin
Sub-system 4: detection and activation of fire protection systems
Sub-system 5: fire service intervention
Sub-system 6: evacuation.

These sub-systems can be expected to interact, e.g. the fire suppression systems will have a major influence on the development of the fire; the spread of smoke will have a major influence on evacuation if the smoke spreads faster than people can evacuate.

The report has not explicitly referred to the sub-systems as such, but it can be readily seen that it follows the same principle of considering these sub-systems for each fire protection zone identified for the building.

3.3 Outline of design strategy

A design strategy was established early in the present study, as a part of the Qualitative Design Review recommended by BSI DD 240: Part 1, 1997.

There are no available fire statistics that identify the incidence of fires in different areas of airports. This is also true of Brussels Airport, Zaventem, itself. Consequently it is not possible to identify the probability of any particular type of ignition source, or of any fire sizes appropriate for design. Instead it is necessary to identify potential hazards, and to assume that any potentially catastrophic fire arising from such hazards are unacceptable. At the same time it is never reasonable to design for the largest possible fire: no-one expects to design a building which will protect its occupants and will survive a fully-loaded aircraft crashing into the building, for example. A judgement as to what is the reasonable worst-case is always needed.

It is proposed that as much of the public area as possible will be kept as a single undivided space: both to allow the architect's vision to be less inhibited by the fire precautions, and to allow maximum freedom for the escape of occupants horizontally as well as through the closest emergency exits.

The methods to be adopted are intended to control, to limit the size of, and/or to contain, any fire incident using a mixture of active and passive fire protection methods. Any serious fire risk is to be contained in a bounded protected volume, thus ensuring that the larger public space is not exposed to a significant threat. The methods used to achieve that protection depend upon the circumstances applying to each hazard and its surroundings.

Fire risks outside these protected areas and within the general circulation space have been identified and quantified both in terms of heat production and in terms of the generation of smoky gases.

This overall strategy is similar to the approach adopted in the recently opened Chep Lap Kok Airport in Hong Kong, although there are many differences of detail, both to improve on the methods used there, and because of the very different architecture of the two buildings.

Mathematical modelling techniques have been used to calculate the consequences of this smoke and heat production in terms of threat to the safety of the occupants and of the structure. Recommendations have been made to the effect that any risk deemed unacceptable should be removed, replaced, or enclosed in a protected space. Such risks include displays, seating, signs including advertising, vending machines, and passengers' carry-on baggage.

The structure of the Pier is such that there is a basic "module" which repeats along the length of the Pier. This has been used as part of the mathematical modelling.

The Means of Escape have been studied using appropriate mathematical modelling of the movement of occupants, and related to the smoke movement results to show that occupants will be able to evacuate without being under threat. It is expected that within those parts of the building fully enclosed within fire-resisting boundaries, Means of Escape can conform to the rules set out in the King's Decree.

All fire protection systems must be designed to be complementary, with an element of built-in redundancy wherever possible in order to give a measure of tolerance to equipment malfunction. Where operation is of critical importance there are recommendations for stringent management procedures to monitor the continuing functionality of the equipment.

Provision of fire-fighting equipment and strategies similar to those in the existing Terminal and Pier B has been adopted.

A fire safety management policy will be drawn up to control practices with respect to housekeeping, maintenance, and working procedures. Rules must be defined and effectively enforced on a day-to-day basis. Special attention will need to be given to transient events such as celebrations and sales promotions.

3.4 Zone-by-Zone Quantitative Analysis

3.4.1 General Introduction

The building is a large and complicated structure, but can be divided into separate (although often interacting) Zones where each Zone can be considered separately in terms of Fire protection measures. These Zones have been identified in the QDR, and are listed below:

a) The Departure/Arrival level of Pier A. The full length will be treated as a single Zone with no separation along its length. This Zone will include the "Boarding Gate" region of the Topaas beneath the lower part of the Topaas roof. Calculations will, where appropriate, treat the space as a succession of interacting modules, each having typically 4 boarding gates and 2 shop (or toilet) "cabins" with technical rooms for HVAC above. "Bussing" gates will be a special-case sub-zone. Fire separation between this level of the Pier and the circulation spaces elsewhere in the Topaas will be introduced.
b) The individual boarding bridges.
c) The baggage handling levels at Platform and Basement.
d) Offices/non-public rooms/corridors in the Topaas.
e) Retail shopping at Platform level in the Topaas.
f) Atrium in the Topaas, including the space beneath the roof.
g) Baggage x-ray area at Arrival/Departure level, Topaas.
h) Business-Class Lounges, Topaas.
i) Technical Rooms, Topaas.
j) Restaurant, Arrivals/Departure level, Topaas.

3.4.2 Arrival and Departure Level, Pier A

3.4.2.1 General

The arrival and departure Level of Pier A is here taken to extend into the lower-roofed area of the Topaas where Boarding Bridges are located. It is a very large volume structure, being nearly 650 metres long, and 38 m wide. This is a single compartment, which clearly fails to comply with the prescriptive requirements of the King's Decree, and which requires Derogations from those requirements.

The principle underlying the present proposals is that a sufficiently small fire will not present a threat in a sufficiently large volume space. This is true of a match lit in a normal domestic room, or of a fire of several Megawatts in the Building Research Establishment's Large Laboratory at Cardington (220 m by 80 m by 55 m high). The volume of the arrivals/departure level in Pier A is also large, but it cannot simply be assumed to be safe. This has been demonstrated.

In the absence of statistical data concerning the incidence of fires in similar areas of airports, it was not possible to make a risk analysis based on probabilities. Instead it is necessary to assess the hazards. That is, to identify what potential fuel materials might be present. It was also necessary to determine how those potential fuel materials might be controlled to reduce the chance of ignition and /or to reduce the consequences of ignition. Alternatively where the potential fuel materials cannot be controlled it was necessary to establish precautions that would prevent the large volume space in the Pier from being adversely affected.

There will always be some uncontrollable potential fuel materials present in the main space of the Pier itself. It was necessary to identify a "plausibly pessimistic" worst case for the resulting fire, and to establish that fire will not affect the safe evacuation of occupants. Once this has been identified, in practice it then becomes sufficient to ensure that the "controllable" potential fuels will only permit smaller fires.

3.4.2.2 Identification of Hazards

It was felt that the potential fuels in Pier A could best be recognised by inspection of the existing Pier B.

Perhaps the most obvious but uncontrollable fuel load consisted of saleable goods in the retail shop units. In Pier A these units will be located in open-fronted "cabins". This permits the adoption of a containment approach for the products of combustion, preventing smoky gases from entering the main space.

Technical Rooms, Toilets, and a number of other smaller rooms also occur in the "cabins" planned for Pier A. Fires in these can also in principle be contained.

The seats at each Boarding Gate represent another potential fuel source, and are to be found throughout the arrival/departure Level.

Perhaps a less obvious source of potential fuel is the baggage carried by the passengers themselves. We have been unable to find any known instance of such bags igniting and causing a fire while in the possession of their owners in airports. Nevertheless, FRS has conducted many fire tests on luggage in recent years for UK commercial clients. Modern bags tend to be made of flammable plastics, which are easy to ignite and which develop a considerable heat output when burning. Consequently, and because none of the previous fire tests had studied, the precise sizes and arrangements of bags used as carry-on luggage, specific fire tests were conducted as part of the present project.
The results of these tests suggested that a fire having a peak heat release rate of 500 kW would be appropriate for the largest fire in this essentially uncontrollable fuel source.

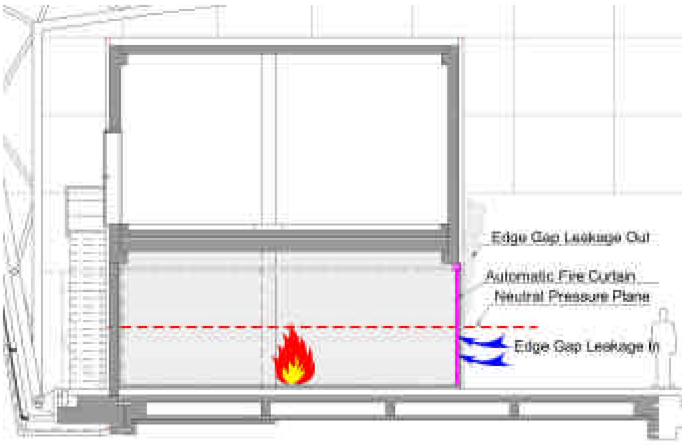
Pier B has many vending machines selling drinks and ice creams. The fire performance of these was not known, so fire tests were also conducted on vending machines. Results suggested that the largest fire involving vending machines would be much smaller than the carry-on bags, and so the vending machines need not be considered further for design purposes.

Other potential sources of fire in the Pier include illuminated advertising signs (which will sustain smaller fires than the baggage); monitors at the Boarding Gates and elsewhere for showing messages (also incapable of burning at the same rate as the bags); desks at the Boarding Gates (which should be made of materials meeting the requirements for Class O under the UK Building Regulations, or the Belgian equivalent); and travelators.

Carpets should also be specified to have a good performance in terms of ignition resistance and of low combustibility. There are few tests for the fire performance of carpets in the horizontal position, but there should be at least a good performance under BS 4790, 1987, or its equivalent.

3.4.2.3 Control of the hazards

3.4.2.3.1 Retail cabins



- Retail units should comply with the detailed recommendations for depressurised cabins.
- The fire safety management procedures for the building should include frequent functional tests of the curtains as a way of detecting faults.
- The smoke curtains should be capable of being motored back into the "everyday" position in order to reduce the intrusiveness of frequent functional tests.
- Staff who sees cabin units on a day-to-day basis should be given the responsibility and the authority to demand that items blocking the smoke curtains be removed, and to report all infringements.
- These staff should also have the duty to remove goods placed outside the line of the smoke curtains at the shop front, and to report all infringements.

- Toilets and other small-room cabins should have outer walls of fire-resisting construction of at least one hour fire resistance.
- They should be fitted with smoke detectors in each room, which trigger an evacuation alarm within that cabin.
- Doors in the perimeter of such cabins should have self-closers, and have smoke seals and intumescent strips.

3.4.2.3.2 Seating within the main space of the Pier

Seating in Pier A should pass fire tests for furniture given in BS 5852, 1990. In our professional opinion, it will not be necessary to use aircraft quality seating. Seating which passes the test with 2 no. 7 cribs and also the cigarette test (source O) will prevent fire spread and limit the fire to a small size.

3.4.2.3.3 Technical Rooms

- Technical rooms should be surrounded by fire-resisting construction rated at least one hour.
- Doors should have self-closers, smoke seals and intumescent strips.
- There should be a smoke detection system in the technical rooms.
- Smoke dampers, rated at the same fire-resistance as the walls, should close off all ducts penetrating the perimeter walls of the technical room. These dampers should be motorised to make it easier to return them to the "everyday" position.
- all fans in the technical rooms should stop on receipt of the same signal that activates the dampers.
- There should be a regular functional test of detectors and of all actions triggered by them as part of the fire safety management procedures for the building.

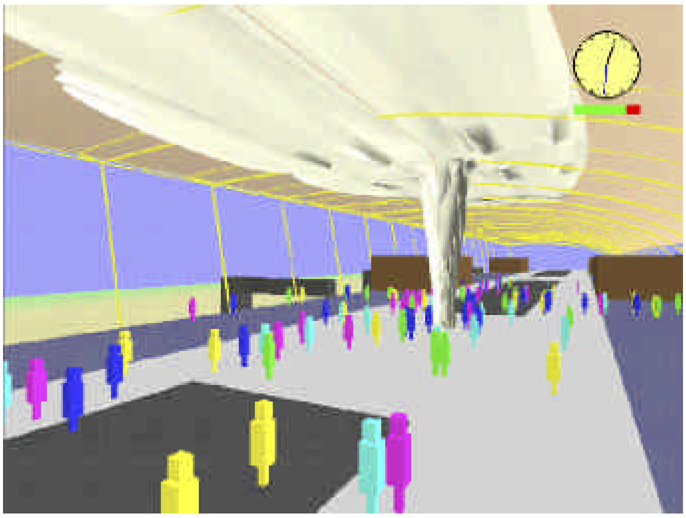
3.4.2.3.4 Travelators

- Exposed surfaces should be essentially incombustible.
- Motor spaces should have an appropriate extinguishing system.

3.4.2.3.5 Other materials in the Pier open spaces

- Illuminated advertising signs in the main Pier space should have translucent screens and casings of inherently low combustibility, for example glass, or fire-retardant treated polycarbonate.
- Desks at Boarding Gates should be constructed to the UK Class O or its equivalent (i.e. in the UK this means Class 1 surface spread of flame BS 476 Part 7, 1987; and low combustibility as defined in paragraph A12 of Approved Document B to the UK Building Regulations, 1991).
- Carpets should have a low surface spread of flame and a low combustibility, *//hot nut test//*.

3.4.2.4 Smoke spread in the Pier and its control



The spread of smoke in such a large structure is not calculable using Zone Model methods. The Computational Fluid Dynamics (CFD) model JASMINE has been used to calculate how the carry-on baggage fire measured in the calorimeter would cause gases to develop and spread along the Pier. Subsidiary calculations have been done to confirm that the model is operating in a fully converged state, and that the results are not distorted by the grid size selected for the main time-based calculation.

The modelling shows that there is no threat to occupants or to the structure from the largest fire likely to affect the main open space in the Pier, even without sprinklers. It follows that this policy of controlling the potentially larger fires by specifying the materials in the Pier, and by confining larger fires within the cabins, makes the fitting of sprinklers in the Pier's main space unnecessary, as there is no job for them to do.

Recommendations

- The HVAC system in the Pier should switch into 100% replacement on detection of smoke in the Pier's ceiling space.
- There is no need for any fire-resistive protection to the steel roof supports in view of the low temperatures to which they will be exposed.
- There is no need for smoke barriers in the roof to create localised smoke reservoirs. Smoke will spread for long distances, but will not move downwards to endanger people or to hinder firefighting.
- There is no need for a sprinkler system to be fitted in the main open space in Pier A.
- The HVAC system will provide a smoke clearance "flushing airflow" after the fire is controlled

3.4.2.5 Evacuation of People from Pier A

Figure A8.3 Evacuation of the Topsas in scenario 1, time = 61 seconds

Figure A8.4 Evacuation of the Topsas in scenario 1, time = 150 seconds

Figure A8.5 Evacuation of the Topsas in scenario 1, time = 300 seconds

Prescriptive rules for Means of Escape, in all Codes world-wide at the time of writing, do not allow for the actual processes taking place in people's minds when the alarm sounds. These rules usually specify travel distances and the widths of the escape path doors, stairs and corridors. They are incapable of estimating the time people will actually need to evacuate the building.

The evacuation of a building may be required for reasons other than a fire in the Pier Arrival Departure Level itself. It may be required as a result of a police emergency, or as a precaution if there is an external fire close to the walls (e.g. a vehicle fire on the roadway close to and below the glazed walls - note that such fires should be considered, and should be reacted to by the Fire Control Room, but are not considered in terms of Building Regulations Approval in most if not all countries.).

The FRS computer model CRISP (Computation of Risk Indices by Simulation Procedures) has been used to model the various stages of human response, and to use probability distributions representing human behaviour both psychological (reaction times) and physical (walking speeds), in order to estimate how long it would take to evacuate the Pier under a variety of assumed scenarios.

Recommendations:

- There should be staff training and active signage to encourage people to evacuate using the nearest boarding bridges, as this leads to shorter evacuation times (4 minutes as opposed to 10 minutes where they are not used.
- There should be staff assigned to meet people evacuating from the boarding bridges and to lead them away from the roadway (leaving it clear for fire service vehicles) and from aircraft hazards on the Apron.
- Security locks on doors leading away from the Pier can be considered, but should release automatically on receipt of a signal sent at the same time as the evacuation alert is initiated.
- The evacuation alerting system needs to inform people of the fire’s location, and give clear directions as to which exits to use. Active signage should be considered to show the appropriate messages.
- Public address announcements, both automatic voice instructions and directed messages based on CCTV observed in the Fire Control room, should be considered to speed and control the evacuation.

3.4.2.6 Smoke Detection in the Pier

Many of the actions, both human and automatic, discussed and recommended in this report need to initiated early in the course of the fire. This usually means that an automatic smoke detection system is required. Either a point detector system or a sampling system would be sufficient within the cabins, but the very large areas of the Pier suggest that other possibilities should be considered.

Recommendations

- Either a system of sampling detectors, or of beam detectors arranged parallel to the long axis of the Pier, should be installed close below the Pier’s ceiling.
- An addressable detector system should be adopted to maximise reliability.
- Point detectors or sampling detectors will be sufficient within the cabins.
- All detectors should be monitored by the Fire Control Room.
- All detector systems must be integrated with, and be compatible with, systems whose actions are initiated by that detection.

3.4.2.7 Boarding Gate Lounge, Platform Level, Topaas.

- The Platform Level Boarding Gate Lounge in the Topaas should be regarded as essentially similar to the main part of the Pier, although with a better provision of egress doors.
- All recommendations concerning the control of materials, and of the exit doors, which have been made for the higher storey of the Pier should be applied here as well.
- A smoke detection system should be fitted beneath the Lounge ceiling.
- When this detector responds to smoke, the HVAC in the Pier above should switch into its emergency mode.

3.4.2.8 Fire-resisting separation between the Pier and the rest of the Topaas

The Pier is here considered to extend into the Topaas structure. The same philosophy of confining the products of large fires, controlling the potential fuel materials’ properties, and using the HVAC system to help to protect people in the main public areas is employed in the remainder of the Topaas as in the Pier. It follows that there ought to be no difficulty in allowing the open space of the Pier to continue uninterrupted through into the Topaas atrium.

Recommendations

- There should be a line of fire/smoke doors between the Pier and the baggage x-ray area of the Topaas.
- These doors should be double swing.
- These doors should be of at least one hour fire resistance.
- The walls and any glazing between other parts of the Topaas, including the Business Class Lounges, should be fire resisting to two hours rating, although glazing could be of one hour's rating due to the controlling effects of sprinklers.

3.4.3 Boarding Bridges

Each Boarding Bridge forms part of an escape route from the Arrival/Departure Level. It is also a fire safety zone deserving of consideration itself.

There is no apparent ignition source, or significant fuel source, within the Boarding Bridge. Even carry-on bags will be with passengers who are usually moving from the boarding gate to the aircraft. It follows that the only fires, which need to be considered, are those outside the bridge. There are essentially three possibilities:

- a fire in the Pier;
- a fire in the aircraft;
- a fire in a vehicle on the roadway directly beneath the bridge.

The problem is that the bridge must be usable as an escape route for either of the first two locations, or rather that the part of the bridge leading to the stairwell half-way along the bridge, plus that stairwell, must remain usable as an escape route.

Recommendations

- There should be a door at the aircraft end of the boarding bridge, which closes (or is released to close) when smoke is detected either in, or close above, the door at the juncture of bridge and Pier.
- The door at the juncture of bridge and Pier should close (or be released to close) when smoke is detected just inside the aircraft end of the bridge.
- Both doors should close on receipt of a signal from a heat detector located on the underside of the bridge above the roadway.

3.4.4 Baggage Handling areas at Platform and Basement Levels in Pier A

An initial survey was made of the existing baggage handling facility in the Terminal Building in order to identify potential hazards.

The outcome of these considerations can be summarised as follows:

- There must be complete horizontal separation between the baggage handling levels and the Arrivals/Departure Level, of at least two hours fire resistance. This applies to smoke and fire dampers needed to close off any ducts penetrating through the slab into the Arrivals/Departures Level above.
- Provided that the other recommendations are followed, there is no need to sub-divide the main spaces, thus allowing them to form a single very large compartment including both levels.
- Estimates, crude in nature but including considerable safety margins, suggest that evacuation and fire fighting will be possible well before smoke conditions become hazardous.
- They further suggest that the sprinkler system is essential to prevent external fire spread out of the large doors at platform level threatening the glazed walls to the Arrival/Departure Level above the door. Note that this aspect means that the sprinkler system is fulfilling a life-safety function and is not only for property protection.

3.4.5 Main Retail Storey, Platform Level, Topaas

This storey is arranged as a shopping mall, forming a ring around the central atrium void. The precise arrangement of retail units is not final at the time of writing, and is likely to change during the lifetime of the building in response to commercial needs. This potential for change makes the "depressurised cabin", or indeed any "cabin" principle unsuitable in this case.

Without smoke control, we can expect large amounts of smoke from a retail unit fire to flow into and to rise through the atrium, adversely affecting the higher floors. It would also necessitate designing the atrium smoke control to cope with a much larger fire than is proposed elsewhere in the present report.

The situation is analogous to the problem facing the smoke control designer looking at a lower storey in a multi-storey shopping mall having too many storeys to allow smoke to rise through the atrium. This problem has been considered, and a solution set out in BS 5588 Part 10, 1991; Morgan & Gardner, 1990; and Hansell & Morgan, 1994. The solution is to position smoke curtains around the atrium void, deep enough to prevent any smoke spilling underneath into the atrium; and to design the remainder of the space as a single-storey shopping mall with a "toroidal" mall surrounding the void.

3.4.6 The atrium in the Topaas

The atrium region of the Topaas extends from the Basement to the roof. Its fuel-load characteristics are similar to Pier A in that there are escalators and lifts (similar to travellators); there are some advertising signs; there are, or may in future be, some seats; and there are the bags being carried by passengers. There is no other significant fire load, since the shops on the platform level are subject to control using a SHEVS design, and all other potential sources of fire can be separated from the atrium by fire-resisting construction.

As in the case of the Pier, it can be seen that the most severe fire to be taken into consideration is a 500 kW fire in carry-on bags. The same arguments apply. The worst-case position for such a fire in terms of affecting evacuation is beneath the ceiling at Basement Level in order to allow the smoke to spread beneath that ceiling before spilling into the atrium void with a resulting large entrainment of air. This has been modelled using JASMINE and the fire development curve measured in the FRS calorimeter and the results suggest that the smoke will not affect the Basement Level, Platform Level, or arrivals/Departures Level escape routes inthe atrium, but will immerse the Mezzanine Level affecting some escape routes from the Business Class Lounges. Nevertheless, even at the Mezzanine Level, the predicted smoke visibility is better than 120 metres, which means that the smoke will be barely noticeable by people using the escape routes on that storey. In other words, the fire is small enough, and the entrainment large enough, for there to be no real hazard to any escape route in the atrium. It also follows from this result that there is little to be gained by having sprinklers underneath any of the ceilings adjacent to the atrium.

The potential for evacuation from the Topaas has been modelled using the program CRISP. The longest times for evacuation appear to be between 8,5 minutes and 10 minutes. While these times are longer than one would like to see in a more normal building, they are still much shorter than any possible time to danger revealed by the CFD modelling. There is some indication that evacuation is quicker if people are better informed as to the best route to follow, although this makes less difference than in the case of the Pier. Good practice suggests, however, that the use of active signage, automatic voice alarm systems, and of staff training to assist in emergency circumstances, would be beneficial.

Recommendations

- It follows that the lifts and escalators should be subject to the same controls as the travellators in the Pier.
- The advertising signs should be subject to the same controls as in the Pier.
- Any carpet should be subject to the same controls as in the Pier.
- There is no need for fire-resisting protection to the steel structure supporting the roof
- There is no need for sprinklers to be fitted beneath the ceilings adjacent to the atrium (excluding the Mall at Platform Level), or at roof level.
- Evacuation through the atrium will continue to be possible at all storeys including the Mezzanine.

- The HVAC system in the atrium should go into 100% replacement when smoke is detected in the atrium. This air should enter near floor level on storeys adjacent to the atrium void, and should be exhausted near the roof.
- Active signage, automatic voice alarm systems, and staff training to assist in emergency circumstances, would be beneficial for evacuation of occupants.
- Smoke detection should consist of beam detectors arranged to detect any appreciable amounts of smoke rising through the atrium voids, as well as sampling detectors close beneath the roof.

3.4.7 Baggage X-Ray Area, Arrivals/Departure Level, Topaas

It has proved impossible to obtain any information on the potential fire behaviour of the x-ray machines themselves. Nevertheless, it is believed that the machines do not represent a significant fire threat, especially as they are usually attended by staff when they are switched on. It is suggested that a sufficient fire precaution might be to provide CO_2 fire extinguishers close to each machine, and to ensure that the security staff manning the machines are trained in their use.

The only other significant fuel sources in this area are the carry-on bags themselves. These will always be present at times when the security staff is also present, and so it can also be expected to be controlled and extinguished rapidly by the staff.

As there are no other sources of fuel in this area, it is reasonable to allow this area to be open to the atrium, and for there to be no sprinklers present.

3.4.8 Business Class Lounges, Topaas

These are mostly on the Mezzanine Level. Inside this fire-resisting perimeter escape routes should comply as far as possible with the King's Decree, although it will be reasonable to regard the atrium as a place of temporary safety for people evacuating from the Lounges in that direction.

Recommendations

- The boundary between the Business Class Lounges and Pier A should be of fire-resisting construction rated at 2 hours, although glazing in that boundary can be of one hour fire resistance.
- The boundary between Lounges and the Topaas atrium should be of fire-resisting construction of at least 2 hours rating.
- All doors in that boundary should be of 2 hours fire resistance and should have self-closers, smoke seals and intumescent strips.
- The Lounges should be fitted with smoke detectors and with sprinklers.

3.4.9 Technical Rooms, Topaas

These are mostly at the topmost storey. They should be dealt with in the same way as the technical rooms in the Pier. That is, they should be of fire-resisting construction in order to contain any fire. Doors into the rooms should be of equal fire resistance, and should have self-closers, smoke seals and intumescent strips. There should be smoke/fire dampers to close off all ducts passing through the walls of the technical room, moving into the fire position on receipt of a signal from the room's smoke detectors. The dampers should be capable of being motored back into the non-fire position to facilitate functional testing.

3.4.10 Restaurant, Arrivals/Departures Level, Topaas

This is the only retail area on this storey in the Topaas. There is no ceiling between the seating area and the roof. The ceiling is too high for efficient operation of sprinklers, and without sprinklers or any control of materials there is a possibility of smoke affecting the Mezzanine Level of the atrium, and probably also requiring fire-resisting protection to the steel structure supporting the roof.

Recommendations

- Kitchens and Servery should be separated from the atrium by fire resisting construction rated at one hour.
- Seats and Tables should be subject to the same test requirements as Boarding Gate seats and desks respectively.

- Sprinklers at ceiling level, and fire protection to the steel above the restaurant, would be unnecessary.

3.4.11 Multi-compartmented regions of the Topaas, not covered by other clauses of this report

Each storey of the Topaas has a mixture of open Public areas connecting through the atrium to other storeys, and rooms which are often connected by corridors to stairwells and/or to the Public areas, but which are not for general public use.

Recommendations

- Non-public regions consisting of rooms and corridors, on all storeys of the Topaas, should be separated from the open public areas by fire-resisting construction rated at two hours.
- Doors in this boundary should have the same fire resistance, should have self-closers, and should have smoke seals and intumescent strips.
- Any doors in this boundary, which are normally held open, should be on electromagnetic devices, which release them to close on receipt of a signal from the smoke detection system.
- Any doors in this boundary, which are normally held open, should be on electromagnetic devices, which release them to close on receipt of a signal from the smoke detection system.

3.6 Fire Safety Management

It has been shown elsewhere in this report that the effectiveness of evacuation of people can be greatly improved by the proper combination of automatic actions supported by the actions of properly trained staff.

All such training can only work best where there has been a high level of advance planning. Pre-planning can be described as the preparation of fire scenarios, and ought to be done by teams including the designers of the fire safety systems as well as management and the emergency services.

Where there are specialised fire safety systems the role of management has to go further. It is essential that there should be regular functional checks on equipment, which might only be needed many years after installation – but where it must then function perfectly. There must be a regular programme of maintenance on such equipment. It is the responsibility of management to ensure that there are procedures in place which will enforce such programmes, and which will prevent the gradual abandonment of safety procedures due to the human tendency towards complacency.

This mixture of pre-planning and ongoing confirmation of readiness should also extend to the role of management in providing assistance to the fire and other emergency services when they arrive to deal with an incident. These plans are generally known as fire intervention plans, and should be fully integrated with the building's fire safety systems and with the fire scenario plans. This latter reason makes it important that the teams drawing up the plans should include representatives of the designers of the fire safety systems, as well as representatives of management and of the emergency services.

A remaining duty of managers falling under the same heading of Fire Safety Management is to continue to monitor the way that changes to the building affect all the abovementioned plans, and how they affect the fire safety installations in the building. It is often good practice for management to discuss proposed changes with the designers of the fire safety systems in case what seems like a minor change turns out to have profound implications for the intended operation of the systems.

Recommendation

Management should prepare a fully integrated Fire Safety Management system including Fire Scenarios, Fire Intervention Plans, Maintenance schedules, and procedures for updating safety provisions of every type as the building and/or its use changes.

5. Further Work

5.1 General

This Section of the report concerns matters which are not covered by the present contract, but the desirability of which are suggested as a result of the work described above. It is only possible to mention these desirable future studies in outline, leaving all detail to the later studies.

5.2 Fire Scenarios

Many of the recommendations made in the present report require that complicated sequences of actions, both automatic and human, have to be carried out in a co-ordinated way. This often applies within each fire protection zone identified in this report, and often is essential to co-ordinate actions in different zones. Some actions, even by the same item of equipment, or by the human agency, are different depending on such factors as the location of the fire.

It is necessary to plan the sequences of interlocking actions in detail for the entire building, to ensure that nothing is missed, and to identify and hence eliminate the possibility of incompatibility between different actions. It is especially important to plan how the emergency actions should interact with the building's normal use.

These plans, once prepared, will form the basis for computer software intended to control the automatic actions of the building systems. They will also form the basis for staff training, by clarifying what training is needed for staff having different roles and working in different locations.

It should also be noted that changes in a building could have major influences on the fire protection measures in that building. It follows that having pre-prepared scenarios not only makes it easier to identify the consequences of any changes, but also make it easy to identify how the protection measures and the fire scenario plans themselves should be changed as well. The fire scenarios must be seen as a dynamic activity, being updated whenever the building is modified, and being consulted whenever modifications are planned.

It follows from this that the fire scenarios should also include procedures to be followed by the building's management at the highest planning levels, as well as at the day-to-day operational levels.

5.3 Fire Intervention Plans

Fire intervention plans are an extension of the fire scenarios to identify procedures, which have a direct relevance to the fire-fighting activities of the fire services. They should cover issues such as how to identify the best access route, depending on the location of the fire identified by the automatic systems and human reports to the Fire Control Room; how best to transmit that information to the fire-fighters in the short time between alarm and their arrival; and what the management and staff can do to assist the fire services to maximise their effectiveness and so to minimise the consequential loss and damage from the fire.

It can be seen that fire intervention plans need to be fully integrated into the fire scenarios. It is also inevitably true that they should be prepared in close collaboration with the fire services having jurisdiction for the airport.

Fire intervention plans, like the fire scenarios, should be regarded as a dynamic concept, needing to be re-examined and modified in the light of any proposed changes to the building, and also in the light of any organisational or equipment changes in the fire service. It can be seen that there will be a need for a continuing dialogue between management and fire service.

This level of planning, both for fire scenarios and for fire intervention plans, and its consequential use in organising the fire safety management of the building is already a feature of the existing Terminal and of Pier B, and it is very desirable that similar preparations are made for the new buildings. Note that IFSET has played a major role in developing and maintaining the fire scenarios and intervention plans in the existing terminal building and in Pier B.

5.4 Hot Smoke Tests

5.4.1 General

Hot smoke tests can take many forms. They can be acceptance tests carried out inside the building itself when the building is close to completion, or they can be specialised off-site tests done to study a specific aspect of the design. Three major types of Hot Smoke Test are suggested by the studies contained in the present report.

5.4.2 Luggage containers - Calorimetry

The design proposals for the baggage handling areas in Pier A were based on an assessment of the fire hazard in the existing baggage handling areas, and in particular on an assessment of the heat release rate of a container full of luggage based on experienced judgement. It would be relatively easy to arrange for a fire test in a large calorimeter, where that calorimeter hood is fitted with sprinklers, to burn such a container and to measure the heat release rate directly.

5.3 Depressurised Cabin

By its nature, the depressurised cabin cannot be tested without allowing high temperatures in the cabin itself. It would be relatively difficult to carry out such a test on site. It would be much easier to create a full-size replica cabin at a test lab and to do as many tests as the Regulatory Authority and/or the Client wish to see. Such a test would have the advantage that it could be done well in advance of the building's completion.

5.4 On-site acceptance tests

It is a matter for the Regulatory Authorities to decide if they require on-site Hot Smoke Tests. We understand that the Fire Authority responsible for the new building has indicated that Hot Smoke Tests should be considered for both the Arrivals/Departures Level of Pier A, and for the Topaas atrium.

We will only note here that FRS and IFSET have collaborated in Hot Smoke Tests in the existing Terminal building, and in the European Parliament Building in Brussels, and that Hot Smoke Tests in either location in the new building would be feasible using our established techniques.

6

This project has been submitted to the Ministry of Interior in Belgium in order to obtain a number of derogations from the Kings Decree.
The Ministry has fully accepted our Fire Safety Report as a whole and derogations have been obtained so that a substantial saving has been achieved.

7 Some important references

British Standards Institution, Fire tests on building materials and structures: Part 7: Method for classification of the surface spread of flame of products, British Standard BS 476: Part 7: 1987. London, BSI, 1987

British Standards Institution. Fire precautions in the design, construction and use of buildings. Part 4: Code of Practice for smoke control using pressure differentials. British Standard BS 5588 Part 4: 1998, London, BSI, 1998

British Standards Institution. Fire precautions in the design, construction and use of buildings. Part 7. Code of practice for the incorporation of atria into buildings. British Standard BS 5588: Part 7: 1997

British Standards Institution. Fire precautions in the design and construction of buildings. Part 10: Code of Practice for shopping complexes, British Standard BS 5588 Part 10, 1991, London, BSI, 1991

British Standards Institution, Fire precautions in the design, construction and use of buildings. Part 11: Code of Practice for shops, offices, industrial, storage and other similar buildings, British Standard BS 5588: Part 11: 1997. London, BSI, 1997

British Standards Institution, Fire Detection and alarm systems for buildings: Part 1: Code of Practice for system design, installation and servicing, British Standard BS 5839: Part 1: 1988. London, BSI, 1988

British Standards Institution, Fire tests for furniture: Methods of test for the ignitibility of upholstered seating by smouldering and flaming ignition sources, British Standard BS 5852, 1990, London, BSI,UK, 1990.

British Standards Institution. Fire Safety Engineering in Buildings Part 1, Guide to the application of fire safety engineering principles. British Standards Draft for Development DD 240: Part 1: 1997. London, BSI. 1997

EN 1021-1: 1993 Furniture – Assessment of the ignitability of upholstered furniture – Part 1: Ignition source: smouldering cigarettes.

EN 1021-2: 1993 Furniture – Assessment of the ignitability of upholstered furniture – Part 2: Ignition source: match flame equivalent.

Hansell G O and Morgan H P. Design approaches for smoke control in atrium buildings. BRE Report BR 258, 1994.

Markatos N.C., Malin M.R. & Cox G., Mathematical modelling of buoyancy induced smoke flow in enclosures. Int. J. Heat Mass transfer, Vol. 25, pp. 63-75, and letter on above: Vol. 25, pp. 1777-1778. (1982)

Morgan H P. Moves towards performance-based standards in the UK and in the European Committee for Standardisation (CEN). Proceedings of the First International Symposium on Engineering Performance-Based Fire Codes. 8 September, Hong Kong, 1998.

Morgan H P, Ghosh B K, Garrad G, Pamlitschka R, De Smedt J-C, Schoonbaert L R, "Design Methodologies For Smoke And Heat Exhaust Ventilation", BR 368, CRC, London, 1999