Smoke Ventilation of Common Access Areas of Flats and Maisonettes (BD2410) - Final Factual Report

Appendix A (Review)

The authors of this report are employed by BRE. The work reported herein was carried out under a Contract placed by the ODPM. Any views expressed are not necessarily those of the ODPM.

Background and general information

An extensive search of the academic and engineering literature has been performed, and the most useful references are included in Appendix G. Appendix A is based largely on the review that was produced as one of the project intermediate outputs [Miles 2004a].

The various smoke management schemes that have previously been considered for common access areas of multi-storey residential buildings, or are currently in use, are described below together with comments on their use and suitability, and relevant research findings where available. Here ‘common access area’ refers to the corridors, lobbies (or vestibules) and stairs that may form the egress path from a unit of accommodation (dwelling) to outside the building. While lift shafts can also be considered as part of the common access region of a building, the smoke management of these is not addressed specifically here.

Following the terminology adopted by Klote and others [Klote & Milke, 2002], the term 'smoke management' in this appendix refers to all methods that can be used to modify the movement of smoke to the benefit of occupants or fire-fighters. This includes pressurisation, natural smoke exhaust etc, which are discussed below. Smoke management measures may be used in isolation or in combination.

The origins of today’s smoke management schemes can be traced back to the work of the late 1960s and 1970s, largely in the UK and North America, which had been commissioned following an increased awareness of the fire dangers associated with high rise buildings, and in particular the problem of smoke spreading away from the compartment of fire origin.

The two building applications where smoke management is most widely used are in the protection of high-rise (commercial and residential) buildings and large (atria etc) spaces such as shopping malls and warehouses. The focus of the current review is on multi-storey buildings, and specifically on residential, multi-dwelling buildings with common escape routes.

Some of the earliest research into smoke control dates from the late 1930s, when the occurrence of fires involving buildings fitted with air handling (HVAC) was studied in the USA, with the recommendation that air handling systems be shut down in the event of fire [NBFU, 1939]. More rigorous studies commenced in the 1960s, when significant work was undertaken in the North America on high-rise building smoke movement [e.g. Tamura, 1969]. At the same time, formative research was conducted also at the UK Fire Research Station, where work on natural (wall opening) ventilation [e.g. Malhortra, 1967] and pressurisation [e.g. Hobson & Stewart, 1972] was undertaken.

Early field studies on real buildings have typically been performed without fire, i.e. a study of the air movement processes due to stack effect etc. Later studies using fire sources were undertaken, with particular focus in the performance of stairwell pressurisation and zone smoke control systems [e.g. DeCicco, 1973].

Various important full-scale smoke control experiments have been conducted at the 10-storey experimental fire tower at the National Research Council of Canada (NRCC), which includes a combination of corridors, stair and lift shafts. The focus of the experiments performed at the NRCC tower has been on establishing the performance of stairwell and lift shaft pressurisation schemes [e.g. Tamura & Klote, 1987] and in providing data for numerical model validation [e.g. Hadjisophocleous et al, 2002]. Experiments have also been undertaken at the experimental building-fire facility at Victoria University of Technology, Australia [see, e.g., He, 1999].

For the purposes of the review, and the project generally, the common access egress path was taken to consist of the following physical components, starting from the fire compartment or dwelling. Where a component is labelled as 'optional', this refers to the fact that this component will not necessarily be present in all cases. As noted already, lifts and lift shafts have been omitted from the.

- Fire compartment. The fire will generally be considered as being within a space open directly to the front door of the fire compartment. Optionally, there may be an internal lobby separating the room of fire origin and the front door.
- Common corridor (optional). There may be one or more corridor / lobby section(s), separated by an appropriate form of compartmentation, e.g. fire door.
- Stair lobby/vestibule (optional). A separate enclosure to provide additional protection to the stair or an area of refuge.
- Vertical stairwell.

The final stage, at the level of final escape, may then include a protected lobby or corridor, or the stair may open directly to the outside.

Before reviewing the various schemes, it is worth noting here the principle mechanisms, or forces, that influence the movement of smoke from the fire source to the rest of the building. The following mechanisms are the principle ones determining the transport of smoke from the location of fire origin.

- Thermal expansion due to heat from the fire. During the growing stage of a compartment fire, provided there are sufficient opening to the compartment then the volume of the gas (air and smoke) inside the compartment will increase in proportion to the increase in absolute temperature inside the compartment. The increased volume is forced out of the compartment into the adjoining spaces. The pressure difference between the compartment and adjoining spaces is determined by the opening area(s), size of the compartment and the rate of temperature rise. Once steady conditions are reached inside the compartment of fire origin, the pressure difference (due to expansion), and the associated expansion flow, reduces to zero.
- Buoyancy forces due to the fire gases. Once the fire is no longer growing, the flow of smoke out of, and air into, a compartment ventilated to adjacent ambient conditions is (ignoring wind effects etc) driven by the buoyancy forces associated

with the hot (smoke) gases. The reduced density inside the fire compartment results in a higher than ambient pressure at ceiling level and a pressure below ambient at floor level, with a resultant flow of hot gas out of the upper vent area(s) and of ambient (cool) air in through the lower opening vent area(s).

- Stack effect in buildings. This is the term applied to the internal flow within a building, either in an upward or downward direction, that is a consequence of a temperature difference between outside environment and that inside the building. The driving mechanism is the same as that for the buoyancy force associated with a fire (heat) source. In 'winter' conditions, where the building internal environment is at a higher than ambient temperature, ambient air enters the building at lower levels, rises through the building and leaves the building at higher levels. In 'summer' conditions, where the building internal environment is at a lower than ambient temperature, the air flow is in the opposite direction. The actual flow paths inside a building are a complex function of internal flow resistances, vent sizes and locations, and the distribution of the internal heating or cooling sources [Tamura, 1994].

  Stack effect pressures can be an important determining factor in the performance of a smoke management system. For example, in severe winter conditions the upward motion of smoke inside stairwells and other vertical shafts is enhanced by the stack forces. Natural smoke venting from vents on the fire floor is particularly influence by stack forces (in addition to wind forces), with or without pressurisation systems present [Tamura, 1978].

- Wind effects. Wind flows around buildings can be highly complex and turbulent, with large variations and length- and time-scales. The resulting distribution of positive and negative wind induced pressures on the building envelope can have a major influence on the performance of the ventilation systems, including that provided for smoke management. Wind induced pressures can effect the performance of natural ventilation [Marchant, 1984] and also mechanical systems including pressurisation [Poreh et al., 2003].

- Forces due to air-handling systems. (This includes pressurisation and smoke ventilation plant). Air-handling (HVAC) systems by their nature can play an important role in determining the movement of smoke. This will often be a detrimental influence, with smoke transported to remote parts of the building, and so a common recommendation is to switch off air-handling systems (not smoke management specific systems) in the event of fire.

  However, the air-handling system can be used to help in the control of smoke. For example, a residential HVAC system may include make-up air supply in the common corridors and exhaust from the lavatories. Such a system, if left running, may help in preventing smoke form entering the common corridors (due to favourable pressure-differentials), and hence protect the non-fire dwellings [Tamura, 1994]. In other applications, the HVAC system can be configured in a fire mode to 'under-pressure' the fire floor relative to adjacent floors, and this protect all non-fire floors. Such systems, known as zone or sandwich pressurisation schemes, are commonly used in office buildings in some parts of the world.

- Piston effect due to movement of lift cars. While the use of lifts as a means of escape in the event of fire is generally discouraged, they do find use in transporting fire-fighters and disabled persons. Lifts cars generate strong suction pressures when in operation, which can interfere strongly with smoke management schemes that are intended to keep smoke out of the lift shaft. The problem is particularly acute with fast moving cars in single lift shafts. Design methods using pressure-differentials have been developed which account for this scenario [Klote & Tamura, 1986].

The above mechanisms are described comprehensively elsewhere [e.g.Tamura, 1994]. Each will produce pressures of varying magnitude, depending on the size of fire, the capacity of mechanical components, climatic/weather conditions and the geometry of the building, ducts, openings etc. Each may then play an important role in how the smoke moves and smoke management schemes function. The relative importance of each mechanism will depend on the individual smoke management scheme and the magnitude of the pressures generated.

Individual smoke management measures, that may be employed singly or in combination, are summarised below. Their use as part of an overall system to provide smoke protection for common access escape routes in residential premises is discussed. In general, a smoke management strategy for common access egress paths will comprise compartmentation (containment by physical barriers) plus one or more passive or active measures.

Smoke management measures for protection of common access areas

Each of the principal smoke management methods that can contribute to the smoke management of common access areas is reviewed below. A summary of the method and its appropriate use is given, and reference to relevant research is provided.

Physical barriers

This refers to floors, walls, doors and other barriers that have sufficient fire resistance to remain ‘intact’ for a specified duration and provide a level of protection against fire and smoke spread from the location of fire origin. Regions of a building that are enclosed within fire-resisting compartmentation elements may be referred top as protected spaces, e.g. corridors and vertical shafts, the latter for example consisting of a stair and lift shaft and possibly, at each storey, a lobby. Note that the term ‘physical barrier’ here includes, as a subset, the elements of compartmentation as described in, for example, [DETR, 2000].

Physical barriers form an integral part of smoke management for egress form high-rise buildings in all cases. Special provisions that may be found for protected internal stair and lift shafts to open to the outside via a dedicated access level protected corridor [Tamura, 1994] or for there to be at least one protected stair that does not extend to basement storeys [DETR, 2000].

Corridors above specified lengths are often required to be divided into ‘sections’ by fire doors, providing additional smoke containment. In the UK [DETR, 2000], for example, the length of undivided corridor is up to 30 m (depending on number of stairwells and ‘dead end’ arrangements), while in New Zealand [BIA, 2001] distances up to 40 m are allowed. Corridor sub-division is generally not required if the corridor itself is protected by a pressurisation scheme. Furthermore, if sprinkler systems are installed inside the dwellings, then the undivided corridor length requirement may be relaxed, as is the case for example in the USA [NFPA, 1992] and New Zealand [BIA, 2001].

In the current project, it was assumed that each of the 'components' of the common access path identified above is separated by a form of fire barrier, e.g. fire-resisting walls and doors.

Dilution (dispersal)

This is known also by the names purging and dispersal. By diluting the smoke concentration sufficiently with fresh air, it is possible to create tenable conditions for persons evacuating along a corridor or down a stairwell. The supply of fresh air may be by natural ventilation (generally openings in external walls) or by mechanical means. For openings in external walls, the pressures generated by the buoyancy of the smoke gases will tend to drive smoke out at higher level and entrain fresh in at lower level.

However, a number of problems have been identified with this method. Firstly, the required volume of fresh air is high, making both mechanical and natural ventilation problematic. Secondly, natural supply and exhaust through vents may be subject to adverse wind and conditions [Marchant, 1984 & Morgan et. al., 1981], and even if functioning satisfactorily, would generally require vents located on different external walls. Thirdly, the performance of natural vents is influenced also by the building stack effect, which may be particularly significant on the upper or lower most floors for taller buildings where there may be a strong tendency for either inflow or outflow from all natural vents on that floor.

Other experiments [e.g. Morgan et. al., 1987] have shown that smoke clearance in corridors by natural dilution/dispersal is not a reliable in terms of maintaining conditions suitable for means of escape, and the performance would be subject strongly to the external environmental conditions. Here smoke was allowed to enter the experimental corridor through door cracks, and a ‘visibility distance’ of 10 m defined conditions acceptable for means of escape. It should be noted that acceptable 'visibility distances' can only be defined in an approximate sense. However, the choice of 10 m can be judged to be a reasonable one for a conservative (safe) analysis, and is recommended by CIBSE [CIBSE, 2003], and is being proposed for inclusion in BSI PD 7974-Part 6 (Evacuation). A good summary on the published work on acceptable visibility distances is provided in [Jin, 2002], where the range of reported distances proposed by various authors is from under 2 m to 20 m. However, the shorter distances correspond generally to conditions where the occupants are familiar with their surroundings or where evacuation is in the context of a 'dash to safety' [e.g. Rasbash, 1967].

A scheme to achieve dilution through the use mechanical extraction, which would provide a designed flow rate and be less susceptible to adverse wind and stack effects, has been proposed [Marshall, 1985], but does not appear to have found favour in practice. A relationship between required mechanically induced flow rate and size of door crack (from the fire compartment to the corridor) to achieve a required smoke density was derived.

Efficient dilution will generally be expected on external corridors and lobbies. While still referenced in various codes and standards, this approach is nowadays not commonplace, in particular where the climatic conditions may be undesirable. External corridors and lobbies are not currently being considered for modelling in the current project.

Smoke dilution using a building HVAC system is unlikely to be effective since the ventilation flow rates will be too low to provide much benefit in conditions [Klote, 1988]. The HVAC system may still have a role to play in zoned smoke control, see below, where its function is to create pressure differentials to prevent smoke spreading away from the storey of fire origin.

A lobby or vestibule is used in some instances, and this acts as an extra line of defence for a protected stairwell or may provide an area of refuge. Vestibules may have no ventilation, or in some instance may be pressurised (on their own or together with the stairwell). An alternative is to vent the vestibule with fresh air, and exhaust at an equal rate [NFPA, 1992], providing in effect a mechanical dilution scheme within the vestibule.

Airflow (critical velocities)

By generating a sufficient horizontal flow of air at the location of the fire it is possible to force all the smoke in one given direction, thus creating safe conditions in the other direction(s). This technique is employed widely in tunnels, where forcing the smoke in a given direction often forms the core of the smoke management strategy, and where other systems such as ceiling level mechanical smoke extraction may present difficulties in respect to installation and maintenance. Furthermore, the geometry of tunnels and the evacuation and fire-fighting strategy will often make this approach attractive, particularly in uni-directional traffic bores.

However, applying an airflow at the source of the fire is not generally considered for buildings, where one problem that has been highlighted is that a high volume of fresh air may 'fan the fire', increasing the likelihood of fire growth. Furthermore, this is not a practical option within residential dwellings. While it could be considered within common access areas such as corridors, it is not appropriate if they are considered as 'sterile', i.e. the fire source is not located here.

Note that achieving a 'critical airflow' remote from the fire source can be considered as part of a successful pressure differential system, where for example the smoke is kept back from protected spaces at open doorways. Here, by maintaining the flow of air above some critical velocity the smoke is 'held back' at the door. However, this method of smoke control is generally considered as part of a pressure differentials scheme and not an airflow control method.

Pressurisation (pressure differentials)

The term pressurisation (or pressure differentials) generally includes the range of schemes whereby designated 'safety critical' regions of the building are protected from the ingress of smoke by maintaining them at a higher pressure than neighbouring spaces.

Pressurisation is widely used worldwide to protect stairwells [e.g. ASHRAE, 1999, BSI, 1998, CEN, 2000, Standards Australia & Standards New Zealand,1998], in particular when they are considered the most important part of the egress route to protect. To eliminate, or at least reduce to acceptable levels, the passage of smoke from the adjacent spaces, the stairwell is maintained at a sufficiently high pressure by means of forced fresh air supply, either at the bottom of the stairwell, the top of the stairwell, or at distributed locations within the height of the stairwell.

Pressurisation may be extended to vestibules and corridors, as specified for example in the UK [BSI, 1998]. However, careful design is require in these cases to ensure that appropriate pressure differentials are maintained between the stairwell, the lobby/vestibule and the corridor. Provision for pressure relief is required at each stage. Unless this is correctly accounted for, the pressures differentials across the various compartmentation boundaries will be reduced or eliminated, rendering the pressurisation system ineffective. Another problem that has been identified is that pressure relief is not properly engineered the pressure differentials may be too great, so that persons (especially the young and weak) cannot open doors on the escape route [NFPA, 2000b].

An alternative to pressurising the stairwell is to pressurise the vestibules only, assuming than that this will protect both the vestibules and the stairwell. This has been practiced in the Japan and elsewhere in the Far East [e.g. Kujime et. al., 1999], where it has been combined with powered smoke extraction from the access corridors. The idea has also been looked at in North America [Tamura, 1980], and is referenced in the Canadian regulations [National Research Council Canada, 1995].

Wind effects, building stack effects and open doors on the stairwell all need to be considered in the design of a stairwell pressurisation system. Quite a lot of research has been undertaken to show that these can all have a significant influence on the pressure distribution inside the stairwell [e.g. Yuill & Haddad, 1994a & 1994b]. The pressurisation system needs to be sized to cope with the expected variations in stack effect, leakage (e.g. door) paths etc. Appropriate pressure relief control may also be required to ensure that the pressure-differentials across closed doors is not so great that it hinders egress.

It has been shown in some cases to be beneficial to distribute the supply of inlet air at multiple locations (storeys) within the stairwell (multiple injection systems) rather than just at the top or bottom (single injection systems). In particular, for buildings greater than about ten storeys in height, single injection systems may be insufficient [Clark & Buckley, 1995]. The North American recommendation is for a maximum of about eight (sometimes up to 12) storeys for a pressurised stairwell served by a single injection system [Klote & Milke, 2002]. An alternative solution to the provision of multiple injection is to divide the stairwell into sections of ,say, eight storeys each. The latter approach is considered less desirable if the anticipated volume of people using the stairwell in case of emergency evacuation is high, as may be the case when the whole building is to be evacuated. Numerical model analysis is generally required in the design of stairwell pressurisation systems involving multiple injection,

There is a well developed body of research into the required pressure-differentials to prevent smoke entering the stairwell, or other protected space, and guidance is widely available. While It is appropriate specify a pressure-difference across a closed door, when the door is open the pressure differential will be 'lost', and in order to prevent smoke ingress to the 'protected' side an airflow (from to protected to unprotected side), above some 'critical' value, is required (see above section on airflow). This has been the subject of various studies [e.g. Tamura, 1992]. The magnitude of the required airflow will be dependent on the temperature of the smoke gases, and so the 'design fire' conditions is important.

A minimum (critical) velocity of air flow (form the high to low pressure side) to prevent smoke propagation into the protected (high pressure) side, is sometimes specified in design codes [e.g. BSI, 1998]. However, there is concern is some quarters, however, that imposing open door airflow criteria generates conditions such that additional oxygen is supplied to the fire, and can make matters more hazardous. In the USA, for example, particular concern has been expressed, and there the building code [International Code Council, 2002] specifically argues against the design of open door velocities greater than 1 ms^{-1}.

It has been shown in experiments that mechanical venting of smoke from the fire space helps the performance of stairwell pressurisation schemes [Tamura, 1990]. The location and size of pressure relief vents on the common corridors, or lobbies, connecting to the pressurised stairwell also needs careful consideration.

In summary, while a properly engineered stairwell pressurisation scheme seems to be an effective way to protect these spaces, the extension of the pressurised space beyond the stairwell is less well ‘understood’. Furthermore, a pressurisation system requires commissioning following installation, so that the fan settings can be adjusted for the operating conditions. And, in common with all systems using mechanical air supply or extract, there is the issue of on-going maintenance of the equipment. This is of particular concern in dedicated smoke control systems, i.e. where the mechanical components are not part of the day-to-day air-handling system, since in the absence or routine maintenance testing the systems may become less reliable with time. An Australian study [Zhao, 1998] highlighted the need for regular maintenance, particularly for components not in regular use. Furthermore, smoke dampers were found to be system component most prone to failure.

Finally, note that some mechanical smoke venting schemes (covered below) can be considered as using the pressure-differential approach, where the vented space is depressurised relative to the adjoining 'protected' spaces.

Zoned smoke control

This is in effect a special application of pressure differentials. The basic concept is to exhaust smoke, generally be mechanical means, from the storey containing the fire and to supply fresh air at a number of storeys above and below. By maintaining the fire storey at a negative pressure relative to the storeys above and below, smoke is kept to this storey and does not spread to other storeys. Typically, the ventilation is provided by the building air-handling system, which in ‘fire mode’ is operated with extract only on the fire storey and supply only (100% fresh air) on the adjacent storeys. While smoke extraction may improve conditions on the fire storey, it is not expected to be sufficient to create tenable conditions for long term exposure. Rather, the main purpose is to create a pressure differential with the adjacent storeys [Klote & Milke, 2002].

It is known also by the term sandwich pressurisation [Marchant, 1992], the terminology referencing the fact that the fire storey at negative relative pressure is ‘sandwiched’ between storeys at positive pressure above and below. It has found favour in other parts of the world for the control of smoke in high-rise commercial (office) buildings, in particular where the occupied space is mainly open plan.

However, it is not considered generally suitable for residential buildings. One reason is that the intention is not to maintain tenable conditions (office staff would be expected to evacuate the fire storey), so that persons asleep for example would be placed in danger. Another reason, in the UK at least, is that the provision for extraction within the dwellings is not considered to be generally practical. Other climates may dictate the general inclusion of air-conditioning systems, so that much of the necessary ducting and plant is already present. But if this plant is not present, then the additional cost associated with a system installed only for smoke control may be excessive.

Natural smoke venting

Dilution and smoke clearance through external wall vents, introduced above, can be classed also as a natural smoke venting scheme. However, the term is more generally applied to schemes where there is an attempt to exhaust smoke at high level and provide replacement fresh air at lower level. By placing vents at high level in the corridor/lobby, there may in the right conditions be a degree of smoke clearance through the vent(s). However, these schemes, as for the dilution methods discussed above, are prone to adverse wind effects.

Smoke shafts have been proposed, and used (in the UK in particular), throughout the world. Some of the early work, particularly in North America, was orientated towards the venting of smoke from the fire compartment itself. However, smoke shafts have also been used to vent smoke from corridors, lobbies and stairwells. While a naturally-ventilated smoke shaft can be expected to work (i.e. draw smoke into the shaft and vent it out of the top) with sufficiently buoyant smoke, they may be prone to adverse wind and building stack effects when the smoke is not sufficiently buoyant [see, for example, Tamura & Shaw, 1973]. Given the condition of cool smoke, for various weather conditions (influencing the building stack pressures in particular) the passage of smoke in a smoke shaft with bottom and top openings could be either upwards or downwards [Tamura & Wilson, 1970].

Where stairwell pressurisation is not employed, there is generally provision for natural venting to 'clear' smoke that enters the stairwell. This will often take the form of a vent at the top of the stairwell, sometimes augmented by vents at ground level and at intermediate storeys. The behaviour of the smoke inside the stairwell, for a given arrangement of ventilation openings, will be influenced strongly by wind building stack effects. It has been suggested [e.g. Poreh & Trebukov, 2000] that there is a benefit in having open vents at the top and bottom of the stairwell, as this gives better overall smoke clearance performance for a wide range of conditions. It is argued that the addition of a bottom vent will in general reduce the amount of smoke passing into the stairwell on the fire floor, and that in ‘adverse’ conditions where the controlling forces dictate a downwards movement of smoke within the stairwell it is the better to have a bottom vent.

The location of vents at rooftop level requires special care [Saathoff et. al., 2002], and the design of the opening may then also be important [Ghosh, 1993]. Given a complex roof top arrangement, the assumption of suction in all weather conditions may be incorrect.

There is no worldwide consensus on the most appropriate way to naturally ventilate stairwells. For example, the Canadian code [National Research Council Canada, 1995] specifies that for a naturally ventilated stairwell the vent be located at ground level so that in winter conditions, where 'reverse stack effects' are significant, conditions are generated such that the whole stairway is at higher pressure than the adjoining building spaces. This then affords smoke protection to the stairway.

Mechanical smoke venting

This refers here to the provision of dedicated smoke exhaust by mechanical means other than that included as part of a zoned smoke control (which will generally utilise the air-handling system) or a mechanical dilution scheme.

Mechanical smoke venting, other than for purely dilution intentions, can be designed to serve two possible purposes. Firstly, it may have the purpose of creating tenable conditions inside the fire compartment, corridor etc. In a long corridor this will require the presence of sufficiently buoyant smoke so that a level of stratification is achieved and smoke can be vented at high level (with replacement fresh air at low level). The second purpose may be to depressurise the space in question, e.g. in a corridor this could help protect an adjacent stairwell in a similar fashion to a formal pressure differential scheme.

A special class of mechanical smoke venting is provided by mechanised smoke shafts. Here the function of the fan could be either to provide a fully-mechanical system (in effect a special form of a ducted mechanical smoke extraction system) [Butcher & Parnell, 1998], or as a ‘background’ assistance to overcome adverse wind or building stack effects. The latter form of smoke shaft would be essentially a natural ventilation device with mechanical assistance. The design of mechanical smoke shafts venting directly from the compartment(s) of fire origin were studied in some depth in the early years of smoke control analysis [e.g. Tamura & Shaw, 1973] are probably most appropriate for office spaces where in Canada design guidance is provided [National Research Council Canada, 1995].

Some guidance on the design of mechanised smoke shafts serving common corridors, adjoining the compartment of fire origin, is now available [CIBSE, 2003], where the system is treated as a type of depressurisation scheme. However, the subject is in its early stages of development and further studies (including the current project) should help establish the required mechanical flow rates and make-up air provisions, or alternatively the design pressure differentials if this approach is appropriate..

With all mechanical smoke venting schemes, the provision for make-up fresh air is particularly important [Butcher & Parnell, 1997]. Furthermore, as with a pressure differentials scheme, care is required to ensure adequate pressure relief paths so that hazards due to doors being held tightly shut are avoided. Here the general guidance is that the pressure differential across a closed door should not exceed about 85 Pa.

Mechanical smoke venting from stairwells is not generally considered as this may, in effect, violate a prime objective of a protected stairwell, which is to eliminate or minimise the passage of smoke from adjacent spaces into the stairwell.

As was stressed in the discussion of pressurisation systems above, the need for on-going maintenance and testing of the mechanical components needs to be considered.

Stairwell lobby access

By separating the stairwell from common corridor(s) / lobby(ies) that adjoin the dwellings by an additional lobby (which does not adjoin any dwelling) additional protection is afforded to the stair. Such lobbies may be unventilated, naturally ventilated or mechanically ventilated (smoke extraction or air supply / pressurisation).

Pressurised vestibules were discussed above under pressurisation. Unventilated lobbies provide additional stair protection by virtue of smoke containment, and are referenced in various regulations [e.g. DETR, 2000]. Elsewhere, naturally or mechanically ventilated lobby (vestibule) access is sometimes specified in cases where the stair in not pressurised [e.g. NFPA, 2000a]. In the USA [International Code Council, 2002], mechanically ventilated vestibules are required to extend vertically by at least 0.5 m above the top of the entrance door, with extraction from this 'smoke trap' space and replacement fresh air at low level.

Limiting the fire size

While this is not a smoke management method in the conventional sense, this may now form part of the analysis, or 'trade-up'. By limiting the size of fire, or by possibly extinguishing it prior to fire service intervention, it has been argued that the requirement for smoke management in the common access areas is reduced, or even eliminated.

The most widely used mechanism for limiting the size of fire in buildings is currently sprinklers, and these are now recommended or required in multi-storey residential premises in various parts of the world, most notably in North America [International Code Council, 2002] and Australasia [Building Industry Authority (New Zealand), 2001]. In some instances, the requirements for smoke management are relaxed if residential sprinklers are installed. However, it is now generally accepted that smoke management remains an important requirement as smoke is still generated when sprinklers are present, and smoke will most likely pass from the fire compartment to the common access areas when the front door to the dwelling is opened. Furthermore, is has been argued that while sprinklers will reduce the temperature of the fire gases, the amount of smoke generated may not be reduced, and in some cases the smoke may be more hazardous in respect to the levels of carbon monoxide [Mawhinney & Tamura, 1994]. Slowly growing and shielded fires pose particular difficulties for sprinkler systems [Williams et. Al., 2004].

Given lower fire gas temperatures and reduced expansion of the air in the fire compartment, a smoke management system using pressure differentials may be ‘helped’ by the presence of sprinklers. Furthermore, the operation of sprinklers will reduce the probability of windows breaking, which eliminates the effect of adverse building stack pressures that may then be generated, and allows for a relaxation in the design pressure differentials in mechanical smoke control systems.

However, there appears to be no formal engineering method to quantify this effect in the design process, and to possibly allow a reduction in the designed pressure differentials, and further research has been recommended in this area [Klote, 1990]. It can be argued that given the uncertainties due to the presence of other controlling mechanisms such as wind pressures and building stack effects, a reduction in the designed pressure differentials is not justified.

There had been some concern that the sudden evaporation of water spray may cause a hazard [Mawhinney & Tamura, 1994]. However, it is generally considered that provided the sprinkler(s) operate early, i.e. before the fire is well developed, then this is not an important issue.

Combined smoke management measures for common access areas of residential high-rise buildings

Physical barriers (smoke containment) may be combined with one of more of the other smoke management measures identified above. Care must then be taken to ensure that the different schemes firstly work individually, and secondly do not compromise one another. This last remark applies especially where pressure differentials are used for some of the common access areas.

While model-scale and full-scale experiments (in addition to tests on real buildings) on high-rise smoke management have been conducted worldwide, there remain unresolved issues in respect to the successful operation of the different approaches. While stairwell pressurisation and natural ventilation are to an extent now understood, the issue of what measures to then apply to corridors, lobbies, vestibules and the compartment/space of fire origin is not clear. Some form of smoke extraction or dilution in the corridors, and possibly vestibules if present, would seem beneficial not only for conditions inside these spaces, but also for the successful operation of the smoke management scheme for the stairwell. Pressurisation of the corridor and/or vestibule may also be of benefit, but the design of these systems is viewed by many as being complicated, and hence perhaps prone to failure.

It is clear that building stack and wind effects can be very important. While these are not easily quantified in a physical-scale model, they can be addressed more readily by numerical modelling.

While the influence of sprinklers acting on the fire source can be expected to generally have a beneficial effect, the interaction with other smoke management components requires careful consideration. Benefits achieved by limiting the fire heat release rate, and hence lowering temperatures and expansion/buoyancy forces, may be offset in part at least by higher volumes of cooler smoke, possible containing greater concentrations of hazardous gases such as carbon monoxide.

An important consideration on the overall smoke management design is the evacuation procedure. While there has been a tendency in the UK to adopt the procedure whereby occupants of non-fire dwellings do not evacuate unless told to do so (e.g. by the Fire Service), in many other parts of the world the preference has been for whole building evacuation. This can have an important bearing on the allowable conditions inside the common corridors and lobbies in particular. However, the whole building evacuation policy has been questioned now in North America [e.g. Proulx, 2001] and the alternative, non-evacuation procedure has been suggested.

Some concluding remarks

A review of previous studies into smoke management for dwellings, corridors, lobbies, stairwells, together with current practice and trends, has been completed. It provided an important input into the choice of fire scenarios and smoke management schemes to investigate in the experimental and numerical modelling programmes of the current research project into the smoke ventilation of common access areas of flats and maisonettes, allowing a set of generic geometries to be proposed, together with the associated smoke ventilation measures.

Smoke management of the common access areas can be divided broadly into that required for the corridors and lobbies, for the stairwell(s) and finally for the lift shaft(s). The focus for the current project is on the corridors and stairwells, for which the range of options available has been reviewed with the emphasis on the appropriateness for residential premises in the UK. While some attention has been given also to smoke management measures that can be used in the compartment of fire origin, these were not pursued further in the current project.

While stairwell smoke management was provided originally by natural ventilation, with combinations of vents at the top, base or at intermediate levels, the worldwide trend over the past decade or so has been towards mechanical pressurisation measures. When properly designed to account for building stack effects, open doorways etc, these schemes can provide smoke-free conditions inside the stairwell for egress and fire-fighting operations. However, in scenarios where absolute smoke-free conditions are not critical, or simplicity of design and maintenance issues are of importance, natural smoke ventilation of the stairwell is still a valid option.

Common corridors and lobbies can also be protected directly by pressurisation systems. However, for residential premises the practice is more generally to provide either natural or mechanical ventilation, or to provide no smoke ventilation measures. In the latter case, it is assumed that the travel distance is sufficiently short or the conditions not too onerous, so that evacuating people can each a stairwell or other area of safety without undue ill effect. This may require, however, that all persons on the fire floor evacuate at an early stage.