In full flow

With new guidance looking afresh at water requirements for firefighting operations, **Paul Grimwood** explains research indicating that design principles and fire service tactics may need to adapt to meet this demand

RECENTLY THERE have been calls in the UK (Water UK 2010)[1] and the USA (NFPA 2014)[2] for a more up-to-date method of determining the optimum quantity of water required for firefighting, based on current data from fire reporting systems. With the recent publication of the British Standards Institution's (BSI's) updated PD 7974-5: 2014: *Application of Fire Safety Engineering Principles to the Design of Buildings – Fire and Rescue Service Intervention*, comes a review of adequate firefighting water requirements (s.8.5) to meet that need.

While fire engineering generally aims to achieve 'equivalence or better than' code compliance during design solutions, this is certainly an area where 'better than code' should be considered in specific situations. During the 1950s/60s there was a collective body of research in the UK that determined the flow-rates (l/min) used by fire brigades to extinguish room and contents fires. The outputs of this research formed the basis for internal rising fire main design and the existing guidance provided by UK Water/Local Government Association (LGA) in terms of planning underground hydrant water supplies for firefighting.

Research-based guidance

A recent research project[3] analysing the impact that inadequate firefighting water provisions might have on fire service intervention strategies, building fire damage and future building design considerations has been undertaken jointly by Glasgow Caledonian University (GCU) and Kent Fire and Rescue Service. This formed the basis of recommendations given in

PD 7974-5, where analysis of data from more than 5,400 building fires occurring across two fire service areas in the UK between 2009 and 2012 suggested that current firefighting water provisions and firefighting facilities in large, tall or complex buildings may not be sufficient to support early interventions dealing with fast developing (growth phase) fires, or extended firefighting operations that lead into the cooling stages (decay phase).

Research showed that developing fires may surpass a point in time at which a successful fire service intervention in large compartments becomes problematic. Once a fire reaches a 20-30 MW level of heat release (depending on accessibility to the fire and resource availability) a minimum flow-rate of 500-750 l/min must be delivered directly onto the fire before it spreads beyond control. If a fire has entered a 'medium to fast' t^2 rate of growth, then this water application must generally be achieved within the first 20 minutes. Without any active or passive fire protection in place, the fire will likely progress into a fast moving 'travelling' fire, devouring office floor plates at speeds in excess of 20m²/min[4], with the potential for uncontrolled fire spread to upper floor levels.

It is acknowledged that the existence of active fire suppression systems will decrease the need for such provisions in fire flow. However, an extremely high level of design, management and maintenance is required throughout the life of a building to ensure that the reliability of any active fire suppression is always close to 100%.

Concerns and solutions

The following are some existing design concerns and fire service tactical solutions:

- there is a logical assumption that 100mm dry rising mains should meet the prescriptive wet rising main flow rate requirement of 1,500 l/min (enough for two to three jets)
- to achieve adequate firefighting water in a dry rising main, there is reliance on the fact that the nearest hydrant can meet this flow demand, but that may not be the case
- it is the fire service that must determine how adequate water can be achieved at height in tall buildings and a tactical water plan should be generated for each building or complex
- the existing guidance to twin 70mm from a single pump into a rising main is problematic in that the first hydrant may not provide 1,500 l/min
- unless three to four collecting heads are provided to fire service pumping appliances, the flow from the first hydrant (say 500 l/min) cannot be augmented without some reconfiguration of pumping arrangements and interruption of flow to the fire floor
- fire service pumping procedure should adapt to parallel pumping arrangements, using single lines of >90mm hose from two separate pumps to feed each riser inlet, with the first arriving pump taking the nearest hydrant and a secondary arriving pump augmenting the second inlet as soon as possible from a pre-selected second hydrant
- this not only enables adequate firefighting water to reach the upper levels, but ensures that a constant flow is maintained should the primary pump fail for any reason
- while 100mm rising mains will generally provide adequate coverage of firefighting water to residential flats and small fire-resisting compartments to 200m², there is a clear need to enable greater flow-rate provisions in unsprinklered compartments larger than 200m² – in such cases, >150mm rising mains provisions are recommended and should still meet maximum prescriptive hose-lay distances, along with the calculated flow-rate density (l/min/m²) recommendations that are provided in BS PD 7974/5: 2014
- water storage provisions and fire service tank-fill connections may also be inadequate where firefighters are expected to maintain an extended firefighting operation for up to two hours per floor of involvement

There is much empirical data that may be used to analyse how fires are likely to develop in the growth stage and burn across large commercial floor space according to variable ventilation parameters and fire load distributions. There is also a vast amount of information available from fire scene videos and firefighters' experiences on the fire floors of major office fires in the UK and USA that offers some comparisons of the importance of adequate firefighting water.

High-rise office fires are nothing new to the UK fire service. When large open-plan office floor plates became involved in fire at the Villiers House fire (London 1979), the Mercantile Credit fire (Basingstoke 1991) and the Telstar House fire (London 2003), firefighters were forced to lay additional hose-lines up stairways to support inadequate flows provided by the 100mm rising mains. These incidents all required large quantities of water to enable firefighters to control and extinguish the fires before the fire limit state was reached and the structural frame failed. In each case, the fires burned in total for more than four hours across several upper floors.

First Interstate Bank fire

A good example of travelling fire spread across large open-plan office floor space is the fire that occurred at the First Interstate Bank building in Los Angeles in 1988. The author visited the site of the fire a few weeks after it occurred and interviewed Los Angeles Fire Department chiefs and firefighters who fought the fire. An analysis of the fire spread on the floor of origin is made of an open-plan office floor space, located around a central core that contained lifts, stairs and service shafts. The office space surrounding the core measured 188m by 7.5m, totalling 1,410 m². The 12th floor fire took 65 minutes to wrap around the core and involve all the available open-plan floor space, and was finally extinguished after two hours. Although a 'medium' t^2 fire growth curve is normally applied to office accommodation, the growth stages in this fire very soon developed a 'fast' rate of growth, spreading through 22m² of floor space per minute.

As the fire developed, a sufficient number of large windows were broken by heat to enable the fire to burn in a fuel controlled state throughout the entire duration of the fire, with 20-25% Av/Af vent opening to floor space ratios fairly constant.

First Interstate Bank Fire 12th Floor Analysis	3 Zone Fire	4 Zone Fire	Entire 12th Floor
Floor area (m²)	470	353	1410
Heat of combustion (MJ/kg)	20	20	20
Fire load energy density MJ/m²	570	570	570
Estimated fire load (kg)	13,253	10,046	40,185
Fire growth rate	Fast	Fast	Fast
Ventilation or fuel controlled	Fuel	Fuel	Fuel
Ventilation opening ratio (%)	25	25	25
Maximum burning rate (kg/s)	5.2	4.3	10.9
Zonal Q_{max} (MW)	104	86	218
Time to uncontrolled burnout (t) (mins)	160	154	185
Time to extinguish (fire service) (mins)	124	124	124

Table 1: Travelling fire analysis at the First Interstate Bank Fire in 1988 (Firesys)

Had the fire floor been modelled as a single compartment fully involved in fire, the estimated energy release – without suppression activity – would have been around 218 MW, based on a fire load energy density of 570 MJ/m² burning at 154 kW/m².

When modelled as a travelling fire (see *Table 1*) advancing through three zonal areas of floor space, the peak energy release (Q_{max}) in each zone is estimated at 104 MW, although there remains an element of additional heat release in adjacent zones as they pre-heat in growth or cool in decay in the far field zones. Even though earlier attempts were made, Los Angeles firefighters were unable to deploy adequate water until 34 minutes into the fire due to a delay in calling the fire department and ineffective fire pump settings serving the wet rising fire mains (standpipes). At this point, almost two thirds of the 12th floor was fully involved in fire.

GCU's research suggests that up to 62% of building fires that have entered a t^2 growth phase will most likely require a large part of the fuel load to be reduced before suppression is finally achieved during the cooling phase. Where large open-plan commercial floor space is involved, the minimum needed flow-rate will be around 6 litres/min/m² of floor fire involvement during the growth phase, reducing to 2 litres/min/m², considered as a critical flow-rate to achieve final suppression during

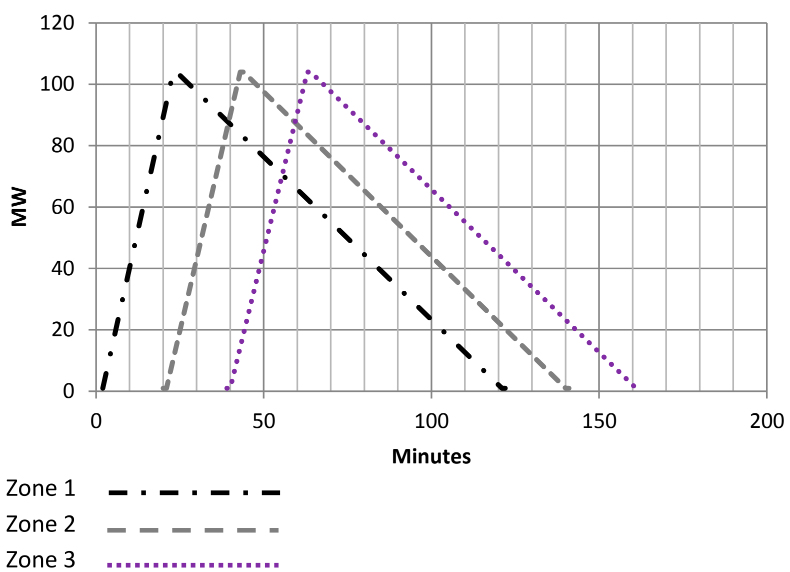

Figure 1: Three-zone model of heat release rates on the 12th floor at the First Interstate Bank 1988

the cooling phase prior to the main structural frame reaching its fire limit state.

Estimating flow-rates

The research by GCU shows an increasing demand for adequate firefighting water (*see Figure 2*) in public buildings, offices, schools, hospitals, hotels and small factories, when compared to fires in private dwellings. The highest flow demands were seen in industrial buildings and storage warehouses. For fires in dwellings (house, flats, maisonettes and apartments):

Equation 1:

$$F_{dwe} = 75 * A_{fire}^{0.44}$$

For fires in factories, industrial units and storage warehouses:

Equation 2:

$$F_{ind} = 131 * A_{fire}^{0.51}$$

For fires in public, office, commercial, schools, hospitals, hotels and smaller industrial buildings (based on the research by Sardqvist s.2.8):

Equation 3:

$$F_{other} = 61 * A_{fire}^{0.57}$$

Where:

- F_{dwe} deployed flow-rate (l/min) for dwellings
- F_{ind} deployed flow-rate (l/min) for factories, industrial and storage warehouses
- F_{other} deployed flow-rate (l/min) for 'all other' buildings (Sardqvist)
- A_{fire} floor area of fire involvement (m^2)

Based on 50% combustion and cooling efficiency factors, Barnett's design calculation correlates well with the water used by UK firefighters to extinguish 5,401 building fires:

Equation 4:

$$F_{design} = 0.00741 * (qk * A_f)^{0.666}$$

Where:

- F_{design} design flow-rate for a fully involved fire compartment burning at maximum intensity (l/s)
- q_k fire load density for the compartment (MJ/m^2)
- A_f total internal floor area of the compartment (m^2)

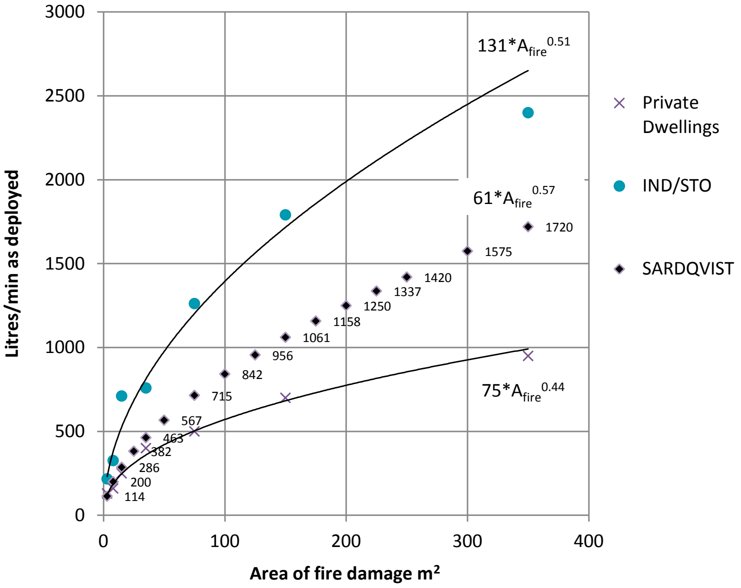

Figure 2: Upper and lower boundary trend lines based on the data collated from the 5,401 UK building fires research 2009-2012 and work by Sardqvist (Equations 1, 2 and 3)

In terms of adequate water for the Interstate Bank Fire, the design flow-rate for the 1,410 m^2 open-plan office floor space at the building can be calculated using Equation (Eq)4, or Eq3 as follows:

$$F_{design} = 0.00741 * (570 * 1410)^{0.666}$$
$$= 3{,}808 \text{ l/min} \quad \text{using Eq4}$$

$$F_{other} = 61 * 1410^{0.57}$$
$$= 3{,}805 \text{ l/min} \quad \text{using Eq3}$$

Where a building fire is releasing much of the heat release to the exterior, through open or vented windows, the water flow-rate demands may be estimated according to the above calculations. However, in some cases the flow path of air to the fire and the direction of smoke and heat release may be affected by internal building pressure differentials or exterior wind. Where a compartment fire reverses the flow of heat release into the building, additional water may be required to achieve fire control. Although a single 500 l/min hose-line will normally deal with a well-involved flat fire (for example), additional hose-lines may be required to deal with corridor gas-phase fire or additional interior fire spread into adjacent flats that may occur in this way.

A good example of an engineered rising main strategy in office buildings can be seen in Singapore, where the vast majority of high-rise office buildings[5] provide adequate firefighting water with a minimum flow in the first riser in use of 2,280 l/min and 1,140 l/min in subsequent risers brought into operation, providing a minimum flow coverage[6] of 2.45 l/min/m^2 on a 1,400m^2 floor plate. These flows are achieved via 150mm wet risers with two outlets per floor per rising main in all office buildings over 45m in height. Storage water for wet risers far exceeds those required in UK commercial buildings ■

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